

6246

~~5372~~

631.8 A115

Acc NO - 5392

C 5:2 M

PRINCIPLES OF MANURING

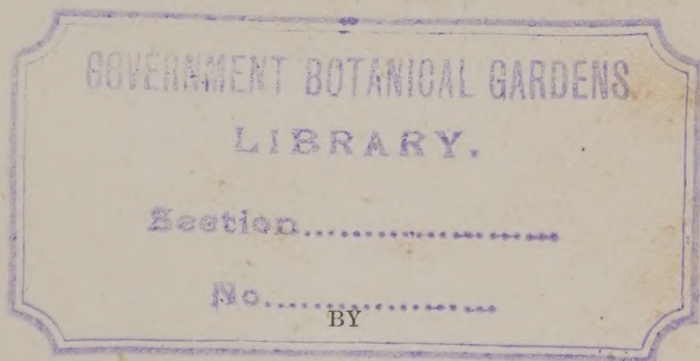




MANU

AND THE

PRINCIPLES OF MANURING



C. M. AIKMAN, M.A., B.Sc., F.R.S.E., F.I.C.



Government of Karnataka

Dr. M. H. Marigowda National Horticulture Library

Directorate Of Horticulture Lalbagh,
Bangalore - 560 004

5392

ACC. No. _____

CALL No. 631.8 AIK

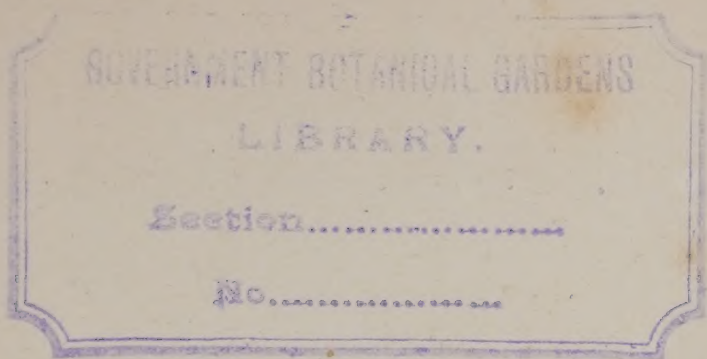
WILLIAM BLACKWOOD AND SONS

EDINBURGH AND LONDON

MDCCCXCIV

631.8

AIK



TO

SIR JOHN BENNET LAWES, BART., D.C.L., LL.D., F.R.S.,
OF ROTHAMSTED,

AND

SIR J. HENRY GILBERT, M.A., LL.D., F.R.S.,
FORMERLY SIBTHORPIAN PROFESSOR OF RURAL ECONOMY,
UNIVERSITY OF OXFORD,

WHOSE FAMOUS INVESTIGATIONS DURING THE LAST FIFTY YEARS
HAVE SO LARGELY CONTRIBUTED TO BUILD UP
THE SCIENCE OF MANURING,

THIS WORK,

EMBODYING MANY OF THE ROTHAMSTED RESULTS,
IS DEDICATED.



PREFACE.

WHEN the present work was first undertaken there were but few works in English dealing with its subject-matter, and hardly any which dealt with the question of Manuring at any length. During the last few years, however, owing to the greatly increased interest taken in agricultural education, the demand for agricultural scientific literature has called into existence quite a number of new works. Despite this fact, the author ventures to believe that the gap which the present treatise was originally designed to fill is still unfilled.

Of the importance of the subject all interested in agriculture are well aware. It is no exaggeration to say that the introduction of the practice of artificial manuring has revolutionised modern husbandry. Indeed, without the aid of artificial manures, arable farming, as at present carried out, would be impos-

sible. Fifty years ago the practice may be said to have been unknown; yet so widespread has it now become, that at the present time the capital invested in the manure trade in this country alone amounts to millions sterling. It need scarcely be pointed out, therefore, that a practice in which such vast monetary interests are involved is worthy of the most careful consideration by all students of agricultural science, as well as, it may be added, by political economists.

The aim of the present work is to supply in a concise and popular form the chief results of recent agricultural research on the question of soil fertility, and the nature and action of various manures. It makes no pretence to be an exhaustive treatise on the subject, and only contains those facts which seem to the author to have an important bearing on agricultural practice. In the treatment of its subject it may be said to stand midway between Professor Storer's recently published elaborate and excellent treatise on 'Agriculture in some of its Relations to Chemistry'—a work which is to be warmly recommended to all students of agricultural science, and to which the author would take this opportunity of acknowledging his indebtedness—and Dr J. M. H. Munro's admirable little work on 'Soils and Manures.'

In order to render the work as intelligible to the ordinary agricultural reader as possible, all tabular matter and matter of a more or less technical nature

have been relegated to the Appendices attached to each chapter.

The author's somewhat wide experience as a University Extension Lecturer, and as a Lecturer in connection with County Council schemes of agricultural education, during the last few years, induces him to believe that the work may be of especial value to those engaged in teaching agricultural science.

He has to express the deep obligation he is under, in common with all writers on Agricultural Chemistry, to the classic researches of Sir John Bennet Lawes, Bart., and Sir J. Henry Gilbert, now in progress for more than fifty years at Sir John Lawes' Experiment Station at Rothamsted. His debt of gratitude to these distinguished investigators has been still further increased by their kindness in permitting him to dedicate the work to them, and for having been good enough to read portions of the work in proof. In addition to the free use which has been made throughout the book of the results of these experiments, the last chapter contains, in a tabular form, a short epitome of some of the more important Rothamsted researches on the action of different manures.

To the numerous German and French works on the subject, more especially to Professor Heiden's encyclopaedic '*Lehrbuch der Düngerlehre*' and the various writings of Dr Emil von Wolff, the author is further much indebted.

Among English works he would especially mention the assistance he has derived from the writings of Mr R. Warington, F.R.S., Professor S. W. Johnson, Professor Armsby, the late Dr Augustus Voelcker, and others. He would also tender his acknowledgments to the new edition of Stephens' 'Book of the Farm,' and he has to thank its editor, his friend Mr James Macdonald, Secretary to the Highland and Agricultural Society of Scotland, for having read parts of his proof-sheets.

It is also his pleasing duty to thank his friends Dr Bernard Dyer, Hon. Secretary of the Society of Public Analysts; Dr A. P. Aitken, Chemist to the Highland and Agricultural Society of Scotland; Professor Douglas Gilchrist of Bangor; Mr F. J. Cooke, late of Fritcham; Mr Hermann Voss of London; and Professor Wright of Glasgow, for having assisted him in the revision of proof-sheets.

ANALYTICAL LABORATORY,
128 WELLINGTON STREET, GLASGOW,

January 1894.

CONTENTS.

PART I.—HISTORICAL INTRODUCTION.

	PAGE
Beginning of agricultural chemistry	4
Early theories regarding plant-growth	4
Van Helmont	4
Digby	6
Duhamel and Stephen Hales	8
Jethro Tull	9
Charles Bonnet's discovery of source of plants' carbon	11
Researches of Priestley, Ingenhousz, Sénéquier, on assimilation of carbon	11-12
Publication of first English treatise by Earl Dundonald	13
Publication of Theodore de Saussure, 'Chemical Researches on Vegetation,' 1804.	14
Theories on source of plant-nitrogen	15
Early experiments on this subject	16
Sir Humphry Davy's lectures (1802-1812)	17
State of agricultural chemistry in 1812	17
Beginning of Boussingault's researches (1834)	21
Publication of Liebig's first report to the British Association	24
Refutation of "humus" theory	26
Liebig's mineral theory	26
Liebig's theory of source of plants' nitrogen	27
Publication of Liebig's second report to British Association	30
Liebig's services to agricultural chemistry	31
Development of agricultural research in Germany	32
The Rothamsted Experiment Station	33

Sir J. B. Lawes and Sir J. H. Gilbert, the nature and value of their experiments	33
Review of the present state of our knowledge of plant-growth	36
Proximate composition of the plant	36
Fixation of carbon by plants	37
Action of light on plant-growth, Dr Siemens' experiments	38
Source of oxygen and hydrogen in the plant	39-40
Source of nitrogen in the plant	40
Relation of the free nitrogen to leguminous plants	42-44
Relation of nitrogen in organic forms, as ammonia salts, and nitrates to the plant	46-50
Nitrification and its conditions	51
Ash constituents of the plant	53
Methods of research for ascertaining essentialness of ash constituents of plants	53
(a) Artificial soils, (b) water-culture	53-55
Method in which plants absorb their food-constituents	55
Endosmosis	55
Retention by soils of plant-food	57
Causes of retention by soils of plant-food	59
Manuring	60
"Field " and "pot " experimentation	60

PART II.—PRINCIPLES OF MANURING.

CHAPTER I.—FERTILITY OF THE SOIL.

What constitutes fertility in a soil	65
I. Physical properties of a soil	66
Kinds of soils	67
Absorptive power for water of soils	67
Absorptive power for water of sand, clay, and humus	68
Fineness of particles of a soil	69
Limit of fineness of soil-particles	69
Importance of retentive power	70
Power of plants for absorbing water from a soil, experiments by Sachs	73
How to increase absorptive power of soils	74
Amount of water in a soil most favourable for plant growth	75
Hygroscopic power of soils	75
Capacity of soils for absorbing and retaining heat	76

Explanation of dew	77
Heat of soils	78
Heat in rotting farmyard manure	78
Causes of heat of fermentation	79
Influence of colour on heat-retaining power	80
Power of soils for absorbing gases	81
Gases found in soils	81
Variation in gas-absorbing power of soils	82
Absorption of nitrogen by soils	82
Requirements of plant-roots in a soil	83
Influence of tillage on number of plants in a certain area	86
Comparison of English and American farming	86
II. Chemical composition of a soil	87
Fertilising ingredients of a soil	87
Importance of <i>nitrogen</i> , <i>phosphoric acid</i> , and <i>potash</i> in a soil	88
Chemical condition of fertilising ingredients in soils	89
Amount of soluble fertilising ingredients in soils	90
Value of chemical analysis of soils	90
III. Biological properties of a soil	92
Bacteria of the soil	92
Recapitulation of Chapter I.	96

APPENDIX TO CHAPTER I.

NOTE

I. Table of absorptive power of soil substances by Schübler	98
II. Table of rate of evaporation of water in different soils by Schübler	99
III. Table of hygroscopic power of soils dried at 212° F. (Davy).	99
IV. Gases present in soil	100
V. Amount of plant-food in soils	100
VI. Chemical composition of the soil	101
VII. Forms in which plant-foods are present in the soil	107

CHAPTER II.—FUNCTIONS PERFORMED BY MANURES.

Etymological meaning of word manure	109
Definition of manures	110
Different classes of manures	111
Action of different classes of manures	113

CHAPTER III.—POSITION OF NITROGEN IN AGRICULTURE.

The Rothamsted experiments and the nitrogen question	115
Different forms in which nitrogen exists in nature	116
Relation of "free" nitrogen to the plant	117
Combined nitrogen in the air	118
Amount of combined nitrogen falling in the rain	119
Nitrogen in the soil	120
Nitrogen in the subsoil	121
Nitrogen of surface-soil	121
Amount of nitrogen in the soil	123
Soils richest in nitrogen	123
Nature of the nitrogen in the soil	124
Organic nitrogen in the soil	125
Differences of surface and subsoil nitrogen	126
Nitrogen as ammonia in soils	127
Amount of ammonia in soils	127
Nitrogen present as nitrates in the soil	128
Position of nitric nitrogen in soil	128
Amount of nitrates in the soil	129
Amount of nitrates in fallow soils	129
Amount of nitrates in cropped soils	130
Amount of nitrates in manured wheat-soils	131
The sources of soil-nitrogen	131
Accumulation of soil-nitrogen under natural conditions	133
Accumulation of nitrogen in pastures	134
Gain of nitrogen with leguminous crops	135
The fixation of "free" nitrogen	136
Influence of manures in increasing soil-nitrogen	136
Sources of loss of nitrogen	137
Loss of nitrates by drainage	137
Prevention of loss of nitrogen by permanent pasture and "catch-cropping"	138
Other conditions diminishing loss of nitrates	139
Amount of loss of nitrogen by drainage	140
Loss of nitrogen in form of "free" nitrogen	141
Total amount of loss of nitrogen	142
Loss of nitrogen by retrogression	142
Artificial sources of loss of nitrogen	144
Amount of nitrogen removed in crops	144

Losses of nitrogen incurred on the farm	146
Loss in treatment of farmyard manure	146
Nitrogen removed in milk	147
Economics of the nitrogen question	147
Loss of nitrogen-compounds in the arts	148
Loss due to use of gunpowder	148
Loss due to sewage disposal	149
Our artificial nitrogen supply	150
Nitrate of soda and sulphate of ammonia	150
Peruvian guano	151
Bones	151
Other nitrogenous manures	152
Oil-seeds and oilcakes	153
Other imported sources of nitrogen	153
Conclusion	153

APPENDIX TO CHAPTER III.

NOTE.

I. Determination of the quantity of nitrogen supplied by rain, as ammonia and nitric acid, to an acre of land during one year	155
II. Nitrogen in soils at various depths	156
III. Nitrogen as nitrates in cropped soils receiving no nitrogenous manures, in lb. per acre (Rothamsted soils)	157
IV. Nitrogen as nitrates in Rothamsted soils	157
V. Examples of increase of nitrogen in Rothamsted soils laid down in pasture	158
VI. Loss by drainage of nitrates	158
VII. Examples of decrease of nitrogen in Rothamsted soils	159
VIII. Amount of drainage and nitrogen as nitrates in drainage-water from unmanured bare soil, 20 and 60 inches deep	160

CHAPTER IV.—NITRIFICATION.

Process of nitrification	161
Occurrence of nitrates in the soil	162
Nitre soils of India	162
Saltpetre plantations	163
Cause of nitrification	165
Ferments effecting nitrification	167
Appearance of nitrous organisms	168
Nitric organism	169

Difficulty in isolating them	169
Nitrifying organisms do not require organic matter	169
Conditions favourable for nitrification—	
Presence of food-constituents	170
Presence of a salifiable base	171
Only takes place in slightly alkaline solutions	172
Action of gypsum on nitrification	173
Presence of oxygen	173
Temperature	175
Presence of a sufficient quantity of moisture	176
Absence of strong sunlight	176
Nitrifying organisms destroyed by poisons	176
Denitrification	177
Denitrification also effected by bacteria	178
Conditions favourable for denitrification	178
Takes place in water-logged soils	179
Distribution of the nitrifying organisms in the soil	179
Depth down at which they occur	180
Action of plant-roots in promoting nitrification	181
Nature of substances capable of nitrification	181
Rate at which nitrification takes place	183
Nitrification takes place chiefly during summer	183
Process goes on most quickly in fallow fields	184
Laboratory experiments on rate of nitrification	185
Certain portions of soil-nitrogen more easily nitrifiable than the rest	187
Rate of nitrification deduced from field experiments	187
Quantity of nitrates formed in the soils of fallow fields	188
Position of nitrates depends on season	188
Nitrates in drainage-waters	188
Amount produced at different times of year	189
Nitrification of manures	190
Ammonia salts most easily nitrifiable	191
Sulphate of ammonia the most easily nitrifiable manure	191
Rate of nitrification of other manures	192
Soils best suited for nitrification	192
Absence of nitrification in forest-soils	193
Important bearing of nitrification on agricultural practice	193
Desirable to have soil covered with vegetation	194
Permanent pasture most economical condition of soil	194
Nitrification and rotation of crops	195

APPENDIX TO CHAPTER IV.

NOTE

I. Old theories of nitrification	196
II. Nitrification takes place in solutions devoid of organic matter	196
III. Oxidising power of micro-organisms in soils	197
IV. Effect of urine on nitrification in soils	197
V. Solution used by Professor Frankland in cultivating nitrificative micro-organisms	198
VI. Experiments by Boussingault on rate of nitrification	198
VII. Nitrogen as nitrates in Rothamsted soils after bare fallow in lb. per acre	198

CHAPTER V.—POSITION OF PHOSPHORIC ACID IN AGRICULTURE.

Occurrence of phosphoric acid in nature	199
Mineral sources of phosphoric acid	200
Apatite and phosphorite	200
Coprolites	201
Occurrence of phosphoric acid in guanos	202
Universal occurrence in common rocks	202
Occurrence in the soil	203
Condition in which phosphoric acid occurs in the soil	203
Occurrence in plants	204
Occurrence in animals	205
Sources of loss of phosphoric acid in agriculture	205
Loss of phosphoric acid by draináge	206
Artificial sources of loss of phosphoric acid	206
Amount of phosphoric acid removed in milk	207
Loss of phosphoric acid in treatment of farmyard manure	208
Loss of phosphoric acid in sewage	208
Sources of artificial gain of phosphoric acid	208

APPENDIX TO CHAPTER V.

NOTE

I. Composition of apatite (Voelcker)	210
II. Percentage of phosphoric acid in the commoner rocks	211

CHAPTER VI.—POSITION OF POTASH IN AGRICULTURE.

Potash of less importance than phosphoric acid	212
Occurrence of potash	213

Felspar and other potash minerals	213
Stassfurt salts	214
Occurrence of saltpetre	215
Occurrence of potash in the soil	215
Potash chiefly in insoluble condition in soils	216
Percentage of potash in plants and plant-ash	216
Occurrence of potash in animal tissue	217
Sources of loss of potash	217
Amount of potash removed in crops	218
Amount of potash removed in milk	218
Potash manures	218

APPENDIX TO CHAPTER VI.

NOTE

I. Amount of potash in different minerals	220
II. Quantity of potash obtained from 1000 lb. of different kinds of vegetation in the manufacture of potashes	220

PART III.—MANURES.

CHAPTER VII.—FARMYARD MANURE.

Variation in its composition	223
Made up of three classes of constituents	224
<i>Solid excreta—</i>	
Its nature	224
Difference in composition of the solid excreta of the different farm animals	224
Causes of this difference	225
Percentage of manurial ingredients in solid excreta of different animals	226
<i>Urine—</i>	
Its nature	228
Variation in its composition	229
Causes of this variation	229
Manurial value of the urine of the different farm animals	230
Percentage of the <i>organic matter, nitrogen, and mineral substances</i> in the food, voided in the solid excreta and urine	232
Comparison of manurial value of total excrements of the different farm animals	234

Nature of changes undergone by food in process of digestion	235
<i>Litter—</i>	
Its uses	236
<i>Straw</i> as litter, and its qualifications	237
Composition of different kinds of straw	238
<i>Loam</i> as litter	239
<i>Peat</i> as litter	240
Comparison of properties of <i>peat-moss</i> and <i>straw</i>	241
The <i>bracken-fern</i> as litter	241
<i>Dried leaves</i> as litter	242
Manures produced by the different animals—	
<i>Horse-manure—</i>	
Amount produced	243
Its nature and composition	243
Amount of straw used for litter	244
Sources of loss on keeping	245
How to prevent loss	245
Use of “fixers,” and the nature of their action	245
<i>Cow-manure—</i>	
Amount produced	248
Its nature and composition	248
Amount of straw used as litter	248
Sources of loss on keeping	249
Advantages of <i>short dung</i>	249
<i>Pig-manure—</i>	
Amount produced	250
Its nature and composition	250
Amount of straw used as litter	251
<i>Sheep-manure—</i>	
Amount produced	251
Nature and composition	251
Amount of straw used as litter	252
Methods of calculating amount of manure produced on the farm	252, note
Fermentation of farmyard manure—	
Action of <i>micro-organic</i> life in producing fermentation	255
Two classes of <i>bacteria</i> active in this work, <i>aerobics</i> and <i>anaerobics</i>	255
Conditions influencing fermentation—	
<i>Temperature</i>	256
<i>Openness to the air</i>	256

<i>Dampness</i>	257
<i>Composition of manure</i>	257
Products of fermentation	257
Analyses of farmyard manure—	
Dr Voelcker's experiments	259
Variation in composition	259
Amounts of <i>moisture, organic matter</i> (containing <i>nitrogen</i>), and <i>mineral matter</i>	260
Its manurial value compared with <i>nitrate of soda, sulphate</i> of <i>ammonia</i> , and <i>superphosphate</i>	260
Comparison of fresh and rotten manure—	
The nature and amount of loss sustained in the process of <i>rotting</i>	261
Ought manure to be applied <i>fresh</i> or <i>rotten</i> ?	262
Relative merits of <i>covered</i> and <i>uncovered</i> manure-heaps . . .	263
Methods of application of farmyard manure to the field—	
Merits and demerits of the different methods	265
Setting it out in <i>heaps</i>	265
Spreading it <i>broadcast</i> , and letting it lie	266
Ploughing it in immediately	267
Value and function of farmyard manure—	
As a supplier of the necessary elements of plant-food . . .	268
As a "universal" manure	269
Proportion in which <i>nitrogen, phosphoric acid</i> , and <i>potash</i> are required by crops	269
Proportion in which they are present in farmyard manure .	270
Farmyard manure <i>poor in nitrogen</i>	270
Lawes' and Gilbert's experiments	271
How it may be best reinforced by the use of "artificials" .	271
Indirect value of farmyard manure as a supplier of <i>humus</i> to the soil	273
Its influence on soil-texture	273
Its influence in setting free inert fertilising matter in the soil	274
Rate at which farmyard manure ought to be applied	275
Lasting nature of farmyard manure	276
Its economic value	276

APPENDIX TO CHAPTER VII.

NOTE

I. Difference in amount of excreta voided for food con- sumed	279
--	-----

NOTE

II. Solid excreta voided by sheep, oxen, and cows	279
III. Urine voided by sheep, oxen, and cows	280
IV. Percentage of food voided in the solid and liquid excrements	281
V. Pig excrements	281
VI. Manurial constituents in 1000 parts of ordinary foods .	282
VII. Analyses of stable-manure, made respectively with peat-moss litter and wheat-straw	283
VIII. Analyses of bracken	283
IX. Analyses of horse-manure	283
X. The nature of the chemical reactions of ammonia "fixers"	284
XI. Analyses of cow-manure	286
XII. Composition of fresh and rotten farmyard manure .	286
XIII. Comparison of fresh and rotten manure	288
XIV. Lord Kinnaird's experiments	289
XV. Drainings of manure-heaps	290
XVI. Amounts of potash and phosphoric acid removed by rotation from a Prussian morgen (.631 acre)	290
XVII. Composition of farmyard manure (fresh)	291
XVIII. The urine (quantity voided)	291

CHAPTER VIII.—GUANO.

Importance in agriculture	293
Influence on British farming	294
Influence of guano not wholly good	295
Value of guano as a manure	296
Origin and occurrence of guano	297
Variation in composition of different guanos	299
I. Nitrogenous guano—	
(a) Peruvian guano	300
Different deposits of Peruvian guano	301
Appearance, colour, and nature of Peruvian guano .	303
Composition of Peruvian guano	304
(b) Other nitrogenous manures: Angamos, Ichaboe .	306
II. Phosphatic guanos—	
Occurrence of phosphatic guanos	308
Inequality in composition of phosphatic guanos	309
"Dissolved" phosphatic guano	310
"Equalised" or "rectified" guano	311

The action of phosphatic guanos as manures	312
Proportion of fertilising constituents in guano	314
Mode of application of guanos	315
Quantity of guano to be used	317
Adulteration of guano	318
So-called guanos—	
Fish-guano	320
Value of fish-guano	322
Meat-meal guano	324
Value of meat-meal guano	324
Bat guano	325
Pigeon and fowl dung	325

APPENDIX TO CHAPTER VIII.

NOTE

I. Peruvian guano imported into United Kingdom, 1865-1893	327
II. Guano deposits of the world	327
III. Composition of concretionary nodules	328
IV. Table showing gradual deterioration of Peruvian guano, 1867-1881	329
V. Composition of different guanos	329
VI. Liebig's theory as to the action of oxalic acid in guano	330
VII. Analyses of dung of fowls, pigeons, ducks, and geese	331

CHAPTER IX.—NITRATE OF SODA.

Amount of exports	332
Date of discovery of nitrate deposits	333
The origin of nitrate deposits	334
Forbes and Darwin on the theory of their origin	335
Source of nitric acid in nitrate of soda	337
Guano theory of origin of nitrate of soda	337
Nitric acid in nitrate of soda probably derived from sea-weed	339
Appearance of nitrate-fields	340
The method of mining the nitrate of soda	341
Composition of <i>caliche</i>	342
Extent of the nitrate deposits	342
Composition and properties of nitrate of soda	343
Nitrate applied as a top-dressing	344
Nitrate of soda encourages deep roots	344

Is nitrate of soda an exhausting manure ?	345
Crops for which nitrate of soda is suited	346
Method of application of nitrate of soda	347
Importance of having a sufficiency of other fertilising constituents	348
Conclusions drawn	349

APPENDIX TO CHAPTER IX.

Total shipments from South America, 1830-1893 . . .	351
Total imports into Europe and United Kingdom, 1873-1892 .	351

CHAPTER X.—SULPHATE OF AMMONIA.

Value of ammonia as a manure	352
Sources of sulphate of ammonia	353
Ammonia from gas-works	353
Other sources	354
Composition, &c., of sulphate of ammonia	355
Application of sulphate of ammonia	356

APPENDIX TO CHAPTER X.

Production of sulphate of ammonia in United Kingdom, 1870-1892	358
---	-----

CHAPTER XI.—BONES.

Early use of bones	359
Different forms in which bones are used	360
Composition of bones	362
The organic matter of bones	363
The inorganic matter of bones	363
Treatment of bones	364
Action of bones	365
Dissolved bones	368
Crops suited for bones	368
Bone-ash	369
Bone-char or bone-black	369

APPENDIX TO CHAPTER XI.

NOTE

I. Analysis of bone-meal	371
II. Analysis of dissolved bones	371
III. Composition of bone-ash	372
IV. Composition of bone-char	372

CHAPTER XII.—MINERAL PHOSPHATES.

Coprolites	373
Canadian apatite or phosphorite	374
Estremadura or Spanish phosphates	375
Norwegian apatite	376
Charlestown or South Carolina phosphate	376
Belgian phosphate	377
Somme phosphate	378
Florida phosphate	378
Lahn phosphate	379
Bordeaux or French phosphate	379
Algerian phosphate	379
Crust guanos	379
Value of mineral phosphates as manures	380

APPENDIX TO CHAPTER XII.

Imports of phosphates	381
---------------------------------	-----

CHAPTER XIII.—SUPERPHOSPHATES.

Discovery of superphosphate by Liebig	382
Manufacture of superphosphate	383
Nature of the reaction taking place	385
Phosphates of lime	385
Reverted phosphate	389
Value of reverted phosphate	391
Composition of superphosphates	391
Action of superphosphates	392
Action of superphosphate sometimes unfavourable	395
Application of superphosphate	395
Value of insoluble phosphates	396
Rate at which superphosphate is applied	397

APPENDIX TO CHAPTER XIII.

NOTE

I. The formulæ, and molecular and percentage composition, of the different phosphates	398
II. Reactions of sulphuric acid and phosphate of lime	398
III. Table for conversion of soluble phosphate into insoluble phosphate	399
IV. Action of iron and alumina in causing reversion	399
V. Relative trade values of phosphoric acid in different manures	400

CHAPTER XIV.—THOMAS-PHOSPHATE OR BASIC SLAG.

Its manufacture	401
Not at first used	403
Discovery of its value as a manure	403
Composition of basic slag	404
Processes for preparing slag	406
Solubility of basic slag	408
Darmstadt experiments with basic slag	410
Results of other experiments	413
Soils most suited for slag	414
Rate of application	414
Method of application	416

APPENDIX TO CHAPTER XIV.

Analysis of basic slag	417
----------------------------------	-----

CHAPTER XV.—POTASSIC MANURES.

Relative importance	418
Scottish soils supplied with potash	419
Sources of potassic manures	419
Stassfurt potash salts	420
Relative merits of sulphate and muriate of potash	421
Application of potash manures	422
Soils and crops suited for potash manures	423
Rate of application	423

CHAPTER XVI.—MINOR ARTIFICIAL MANURES.

Scutch	427
Shoddy and wool-waste	427
Soot	428

CHAPTER XVII.—SEWAGE AS A MANURE.

Irrigation	431
Effects of continued application of sewage	433
Intermittent irrigation	434
Crops suited for sewage	434
Treatment of sewage by precipitation, &c.	436
Value of sewage sludge	439

CHAPTER XVIII.—LIQUID MANURE 442

CHAPTER XIX.—COMPOSTS.

Farmyard manure a typical compost	446
Other composts	447

CHAPTER XX.—INDIRECT MANURES.

Lime	449
Antiquity of lime as a manure	449
Action of lime	449
Lime a necessary plant-food	450
Lime of abundant occurrence	452
Lime returned to the soil in ordinary agricultural practice	452
Different forms of lime	453
Caustic lime	453
Lime acts both mechanically and chemically	455
I. Mechanical functions of lime	455
Action on soil's texture	455
Lime renders light soils more cohesive	457
II. Chemical action of lime	457

III. Biological action of lime	459
Action of lime on nitrogenous organic matter	460
Recapitulation	461

CHAPTER XXI.—INDIRECT MANURES—GYPSUM, SALT, ETC.

Gypsum	462
Mode in which gypsum acts	462
Salt	465
Antiquity of the use of salt	465
Nature of its action	465
Salt not a necessary plant-food	466
Can soda replace potash?	466
Salt of universal occurrence	467
Special sources of salt	468
The action of salt	468
Mechanical action on soils	470
Solvent action	470
Best used in small quantities along with manures	472
Affects quality of crop	472
Rate of application	473

CHAPTER XXII.—THE APPLICATION OF MANURES.

Influence of manures in increasing soil-fertility	474
Influence of farmyard manure on the soil	475
Farmyard manure <i>v.</i> artificials	476
Farmyard manure not favourable to certain crops	477
Conditions determining the application of artificial manures	477
Nature of the manure	478
Nitrogenous manures	478
Phosphatic manures	480
Potash manures	480
Nature of soil	481
Nature of previous manuring	482
Nature of the crop	483
Amounts of fertilising ingredients removed from the soil by different crops	481
Capacity of crops for assimilating manures	486
Difference in root-systems of different crops	488

Period of growth	489
Variation in composition of crops	490
Absorption of plant-food	490
Fertilising ingredients lodge in the seed	491
Forms in which nitrogen exists in plants	491
Bearing of above on agricultural practice	492
Influence of excessive manuring of crops	492

CHAPTER XXIII.—MANURING OF THE COMMON FARM CROPS.

Cereals	493
Especially benefited by nitrogenous manures	494
Power of absorbing silicates	494
Barley	495
Period of growth	495
Most suitable soil	496
Farmyard manure not suitable	497
Importance of uniform manuring of barley	497
Norfolk experiments on barley	497
Proportion of grain to straw	498
Wheat	499
Rothamsted experiments	500
Continuous growth	500
Flitcham experiments	500
Oats	501
A very hardy crop	502
Require mixed nitrogenous manuring	502
Arendt's experiments	503
Avenine	503
Quantities of manures	504
Grass	504
Effect of manures on herbage of pastures	505
Influence of farmyard manure	506
Influence of soil and season on pastures	507
Manuring of meadow land	508
Bangor experiments	508
Norfolk experiments	509
Manuring of permanent pastures	509
Roots	510
Influence of manure on composition	512
Nitrogenous manures increase sugar	512

Amount of nitrogen recovered in increase of crop	513
Norfolk experiments	513
Manure for swedes	514
Highland Society's experiments	515
Manuring for rich crops of turnips	516
Experiments by the author on turnips	516
Potatoes	517
Highland Society's experiments	518
The Rothamsted experiments	519
Effect of farmyard manure	520
Manuring of potatoes in Jersey	521
The influence of manure on the composition	521
Leguminous crops	522
Leguminous plants benefit by potash	523
Nitrogenous manures may be hurtful	523
Clover sickness	524
Alternate wheat and bean rotation	524
Beans	525
Manure for beans	525
Relative value of manurial ingredients	526
Gypsum as a bean manure	526
Effect of manure on composition of crop	527
Peas	527
Hops	528
Cabbages	528

APPENDIX TO CHAPTER XXIII.

Experiments on bean-manuring	530
--	-----

CHAPTER XXIV.—ON THE METHOD OF APPLICATION,
AND ON THE MIXING OF MANURES.

Equal distribution of manures	531
Mixing manures	532
Risks of loss in mixtures	533
Loss of ammonia	533
Effects of lime on ammonia	535
Loss of nitric acid	536
Reversion of phosphates	537
Manurial ingredients should be applied separately	538

CHAPTER XXV.—ON THE VALUATION AND ANALYSIS OF MANURES.

Value of chemical analysis	539
Interpretation of chemical analysis	539
Nitrogen	540
Phosphoric acid	541
Importance of mechanical condition of phosphate	542
Potash	542
Other items in the chemical analysis of manures	543
Fertilisers and Feeding Stuffs Act	543
Different methods of valuing manures	544
Unit value of manurial ingredients	544
Intrinsic value of manures	545
Field experiments	545
Educational value of field experiments	547
Value of manures deduced from experiments	548
Value of unexhausted manures	549
Potential fertility of a soil	549
Tables of value of unexhausted manures	551

APPENDIX TO CHAPTER XXV.

NOTE

I. Factors for calculating compounds from manurial ingredients	553
II. Units for determining commercial value of manures and cash prices of manures	554, 555
III. Manurial value of nitrogen and potash in different substances	556
IV. Comparative manurial value of different forms of nitrogen and potash	557
V. Lawes' and Gilbert's tables for calculating unexhausted value of manures	559

CHAPTER XXVI.—THE ROTHAMSTED EXPERIMENTS.

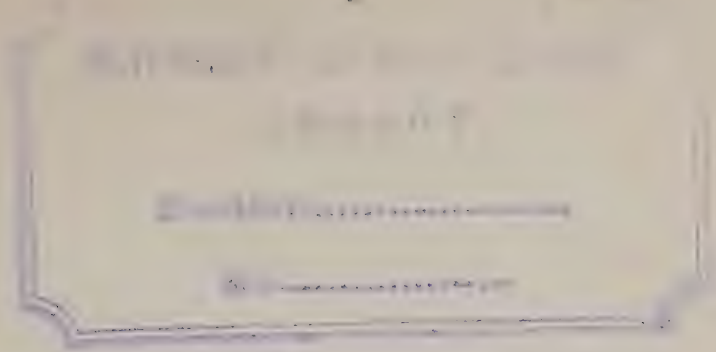
Nature of experiments on crops and manures	561
Soil of Rothamsted	561
Table I. List of Rothamsted field experiments	562
Wheat experiments—	
Unmanured plots	562

Wheat grown continuously on same land (unmanured)	. 562
Table II. Results of first eight years	. 562
" III. Results of subsequent forty years	. 562
Table IV. Wheat grown continuously with farmyard manure (14 tons per annum)	. 564
" V. Wheat grown continuously with artificial manures	. 565
Table VI. Experiments on the growth of barley, forty years, 1852-91	. 566
" VII. Experiments on the growth of oats, 1869-78	. 567
" VIII. Experiments on root crops—swedish turnips	568, 569
" IX. Experiments on mangel-wurzel	. 568, 569
" X. Experiments with different manures on permanent meadow-land, thirty-six years, 1856-91	. 570
" XI. Experiments on the growth of potatoes—average for five seasons, 1876-80	. 571
" XII. Experiments on growth of potatoes (continued)—average for twelve seasons, 1881-92	. 572

INDEX	. 573
-------	-------

PART I.

HISTORICAL INTRODUCTION



MANURES AND THE PRINCIPLES OF MANURING.

HISTORICAL INTRODUCTION.

AGRICULTURAL CHEMISTRY, like most branches of natural science, may be said to be entirely of modern growth. While it is true we have many old speculations on the subject, they can scarcely be said to possess much scientific value. The great questions which had first to be solved by the agricultural chemist were,—What is the food of plants? and,—What is the source of that food? The second of these two questions more easily admitted of answer than the first. The source of plant-food could only be the atmosphere or the soil. As the composition of the atmosphere, however, was not discovered till the close of last century, and the chemistry of the soil is a question which is still requiring much work

ere we shall be in possession of anything like a full knowledge of it, it will be at once obvious that the very fundamental conditions for a solution of the question were wanting. The beginning, then, of a true scientific agricultural chemistry may be said to date from the brilliant discoveries associated with the names of Priestley, Scheele, Lavoisier, Cavendish, and Black—that is, towards the close of last century.

Early Theories on Source of Plant-food.

While this is so, and while we must regard the early attempts made towards solving this question as being, for the most part, of little scientific value, it is not without interest, from the historical point of view, to glance briefly at some of these old interesting speculations.

The Aristotelian doctrine, regarding the possibility of dividing matter into the so-called four primary elements, *fire, air, earth, and water*, which obtained in one form or another till the birth of modern chemistry, had naturally an important influence on these early theories.

Van Helmont's Theory.

Among the earliest and most important attempts made to solve the problem of plant-growth was that by Jean Baptiste Van Helmont, one of the best known of the alchemists, who flourished about the beginning of the seventeenth century. Van Helmont believed

that he had proved by a conclusive experiment that all the products of vegetables were capable of being generated from water. The details of this classical experiment were as follows:—

“He took a given weight of dry soil—200 lb.—and into this soil he planted a willow-tree that weighed 5 lb., and he watered this carefully from time to time with pure rain-water, taking care to prevent any dust or dirt falling on to the earth in which the plant grew. He allowed this to go on growing for five years, and at the end of that period, thinking his experiment had been conducted sufficiently long, he pulled up his tree by the roots, shook all the earth off, dried the earth again, weighed the earth and weighed the plant. He found that the plant now weighed 169 lb. 3 ounces, whereas the weight of the soil remained very nearly what it was—about 200 lb. It had only lost 2 ounces in weight.”¹

The conclusion, therefore, come to by Van Helmont was that the source of plant-food was *water*.²

¹ The History of the Chemical Elements. By Sir Henry E. Roscoe, F.R.S. (Wm. Collins, Sons, & Co.)

² Van Helmont's science was, however, of an extremely rudimentary nature, as may be evidenced by the belief he entertained that the smells which arise from the bottom of morasses produce frogs, slugs, leeches, and other things; as well as by the following recipe which he gave for the production of a pot of mice: “Press a dirty shirt into the orifice of a vessel containing a little corn, after about twenty-one days the ferment proceeding from the dirty shirt, modified by the odour of the corn, effects a transmutation of the wheat into mice.” The crowning point in this recipe, however, lay in the fact that he

Digby's Theory.

Some fifty years later an extremely interesting book was published bearing the following title: 'A Discourse concerning the Vegetation of Plants, spoken by Sir Kenelm Digby, at Gresham College, on the 23d of January 1660. (At a meeting of the Society for promoting Philosophical Knowledge by Experiments. London: Printed for John Williams, in Little Britain, over against St Botolph's Church, 1669.)' The author attributes plant-growth to the influence of a *balsam* which the air contains. This book is especially interesting as containing the earliest recognition of the value of saltpetre as a manure. The following is an extract from this interesting old work:—

"The sickness, and at last the death of a plant, in its natural course, proceeds from the want of that balsamick saline juice; which, I have said, makes it swell, germinate, and augment itself. This want may proceed either from a destitution of it in the place where the plant grows, as when it is in a barren soil or bad air, or from a defect in the plant itself, that hath not vigour sufficient to attract it, though it be within the sphere of it; as when the root has become

asserted that he had himself witnessed the fact, and, as an interesting and corroborative detail, he added that the mice were born full-grown. See 'Louis Pasteur: His Life and Labours.' By his Son-in-law. Translated by Lady Claud Hamilton. (Longmans, Green, & Co.) P. 89.

so hard, obstructed and cold, as that it hath lost its vegetable functions. Now, both these may be remedy'd, in a great measure, by one and the same physick. . . . The watering of soils with cold hungray springs doth little good ; whereas muddy saline waters brought to overflow a piece of ground enrich it much. But above all, well-digested dew makes all plants luxuriate and prosper most. Now what may it be that endues these liquors with such prolifick virtue ? The meer water which is common to them all, cannot be it ; there must be something else enclosed within it, to which the water serves but for a vehicle. Examine it by spagyric art, and you will find that it is nothing else than a *nitrous salt*, which is dilated in the water. It is this salt which gives fœcundity to all things : and from this salt (rightly understood) not only all vegetables, but also all minerals draw their origine. By the help of plain *salt-peter*, dilated in water and mingled with some other fit earthy substance, that may familiarize it a little with the corn into which I endeavoured to introduce it, I have made the barrenest ground far out-go the richest, in giving a prodigiously plentiful harvest. I have seen hemp-seed soaked in this liquor, that hath in due time made such plants arise, as, for the tallness and hardness of them, seemed rather to be coppice-wood of fourteen years' growth at least, than plain hemp. The fathers of the Christian doctrine at Paris still keep by them for a monument (and indeed it is an admirable one)

a plant of barley consisting of 249 stalks, springing from one root or grain of barley ; in which they counted above 18,000 grains or seeds of barley. But do you think that it is barely the salt-peter, imbibed into the seed or root, which causeth this fertility ? no : that would be soon exhausted and could not furnish matter to so vast a progeny. The salt-peter there is like a magnet, which attracts a like salt which fœcundates the air, and gave cause to the Cosmopolite to say there is in the air a hidden food of life.”¹

Duhamel and Hales.

The names of the French writer, Duhamel, and of the English, Stephen Hales, may be mentioned in passing as authors of works bearing on the question of vegetable physiology. Both of these writers flourished about the middle of the eighteenth century. The writings of the former contained much valuable information on the effects of grafting, motion of sap, and influence of light on vegetable growth, and also the results of experiments which the author had carried out on the influence of treating plants with certain substances. ‘*Statical Essays, containing Vegetable Staticks ; or an Account of some Statical Experiments on the Sap of Vegetables, by Stephen Hales, D.D.*’ (2

¹ He then goes on to relate a number of experiments by Cornelius Drebel and Albertus Magnus, showing the refreshing power of this balsam, and then those of Quercitan with roses and other flowers, and his own with nettles.

vols.), was published in London in 1738; and contained, as will be seen from its title, records of experiments of very much the same nature as those of Duhamel.

Jethro Tull's Theory.

Some reference may be made to a theory which created a considerable amount of interest when it was first published—viz., that of Jethro Tull. The chief value of Tull's contribution to the subject of agricultural science was, that he emphasised the importance of tillage operations by putting forward a theory to account for the fact, universally recognised, that the more thoroughly a soil was tilled, the more luxuriant the crops would be. As Tull's theory had a very considerable influence in stirring up interest in many of the most important problems in agricultural chemistry, and as it contained in itself much, the value of which we have only of late years come to understand, a brief statement of this theory may not be without interest.

According to Tull the food of plants consists of the particles of the soil. These particles, however, must be rendered very minute before they become available for the plant, which absorbs them by means of its root-lets. This pulverisation of the soil goes on in nature independently of the farmer, but only very slowly, and the farmer has therefore to hasten it on by means of tillage operations. The more efficiently these operations are carried on, the more abundant will the supply

of plant-food be rendered in the soil. He consequently introduced and advocated the system of horse-hoe husbandry. This theory, he informs us, was suggested to him by the custom, which he had noticed on the Continent, of growing vines in rows, and hoeing the intervals between these rows from time to time. The excellent results which followed this mode of cultivation induced him to adopt it in England for his farm crops. He accordingly sowed his crops in rows or ridges, wide enough apart to admit of thorough tillage of the intervals by ploughing as well as by hand-hoeing. This he continued until the plant had reached maturity. As to the exact width of the interval most suitable, he made a large number of experiments. At first, in the cultivation of wheat, he made this interval six feet wide; but latterly he adopted an interval of lesser width, that finally arrived at being between four and five feet. He likewise experimented on each separate ridge as to which was the best number of rows of wheat to be sown, latterly adopting, as most convenient, two rows at ten inches apart. The great success which he met with in this system of cultivation induced him to publish the results of his experiments in his famous work, 'Horse-Hoeing Husbandry.'

While Tull's theory was based on principles at heart thoroughly sound, he was carried away by his personal success into drawing unwarrantable deductions. Thus he came to the conclusion that rotation

of crops was unnecessary, provided that a thorough system of tillage was carried out. Manures also, according to him, might be entirely dispensed with under his system of cultivation, for the true function of all manures is to aid in the pulverisation of the soil by fermentation.

The first really valuable scientific facts contributed to the science were made by Priestley, Bonnet, Ingenhousz, and Sénéquier.

Discovery of the Source of Plants' Carbon.

To Charles Bonnet (1720-1793), a Swiss naturalist, is due the credit of having made the first contribution to a discovery of very great importance—viz., the true source of the *carbon*, which we now know forms so large a portion of the plant-substance. Bonnet, who had devoted himself to the question of the function of leaves, noticed that when these were immersed in water bubbles were seen, after a time, to collect on their surface. De la Hire, it ought to be pointed out, had noticed this same fact about sixty years earlier. It was left to Priestley, however, to identify these bubbles with the gas he had a short time previously discovered—viz., oxygen. Priestley had observed, about this time, the interesting fact that plants possessed the power of purifying air vitiated by the presence of animal life.¹ The

¹ Priestley, however, did not realise that *carbonic acid gas* was a necessary plant-food; on the contrary, he considered it to have a

next step in this highly interesting and important discovery was taken by John Ingenhousz (1730-1799), an eminent physician and natural philosopher. In 1779, Ingenhousz published a work in London entitled 'Experiments on Vegetables.' In it he gives the results of some important experiments he had made on the question already investigated by Bonnet and Priestley. These experiments proved that plant-leaves only gave up their oxygen in the presence of sunlight. In 1782 he published another work on 'The Influence of the Vegetable Kingdom on the Animal Creation.'¹

The source of the gas, which Bonnet had first noticed to be given off from plant-leaves, Priestley had identified as oxygen, and Ingenhousz had proved to be only given off under the influence of the sun's rays, was finally shown by a Swiss naturalist, Jean Sénébier² (1742-1809), to be the *carbonic acid gas* in the air, which the plant absorbed and decomposed, giving out the oxygen and assimilating the carbon.

deleterious action on plant-growth. Percival was really the first to point out that carbonic acid gas was a plant-food.

¹ It is recorded as an instance of the scientific enthusiasm of the man, that he was wont to carry about with him bottles containing oxygen, which he had obtained from cabbage-leaves, as also coils of iron wire, with which he could illustrate the brilliant combustion which ensued on burning the latter in oxygen gas.

² For a full account of Sénébier's researches, see 'Physiologie végétale, contenant une description des organes des plantes, et une exposition des phénomènes produits par leur organisation, par Jean Sénébier.' (5 tomes. Genève, 1800.)

Publication of First English Treatise on Agricultural Chemistry.

In 1795, a book dealing with the relations between chemistry and agriculture was published. This work was written by a Scottish nobleman, the Earl of Dundonald, and possesses especial interest from the fact that it is the first book in the English language on agricultural chemistry. The full title is as follows: 'A Treatise showing the Intimate Connection that subsists between Agriculture and Chemistry.'

In his introduction the author says: "The slow progress which agriculture has hitherto made as a science is to be ascribed to a want of education on the part of the cultivators of the soil, and to a want of knowledge, in such authors as have written on agriculture, of the intimate connection that subsists between the science and that of chemistry. Indeed, there is no operation or process not merely mechanical that does not depend on chemistry, which is defined to be a knowledge of the properties of bodies, and of the effects resulting from their different combinations."

In quoting this passage Professor S. W. Johnson remarks:¹ "Earl Dundonald could not fail to see that chemistry was ere long to open a splendid future for the ancient art that had always been and always will be the prime supporter of the nations. But when he

¹ *How Crops Grow*. By Professor S. W. Johnson. Macmillan & Co. (Introduction, p. 4.)

wrote, how feeble was the light that chemistry could throw upon the fundamental questions of agricultural science! The chemical nature of the atmosphere was then a discovery of barely twenty years' standing. The composition of water had been known but twelve years. The only account of the composition of plants that Earl Dundonald could give was the following: 'Vegetables consist of mucilaginous matter, resinous matter, matter analogous to that of animals, and some proportion of oil. . . . Besides these, vegetables contain earthy matters, formerly held in solution in the newly-taken-in juices of the growing vegetables.' To be sure, he explains by mentioning in subsequent pages that starch belongs to the mucilaginous matter, and that on analysis by fire vegetables yield soluble alkaline salts and insoluble phosphate of lime. But these salts, he held, were formed in the process of burning, their lime excepted; and the fact of their being taken from the soil and constituting the indispensable food of plants, his lordship was unacquainted with. The gist of agricultural chemistry with him was, that plants 'are composed of gases with a small proportion of calcareous matter; for although this discovery may appear to be of small moment to the practical farmer, yet it is well deserving of his attention and notice.'"

De Saussure.

The year 1804 witnessed the publication of by far the most important contribution made to the science

up till this time. This was 'Recherches Chimique sur la Végétation,' by Theodore de Saussure, one of the most illustrious agricultural chemists of the century. De Saussure was the first to draw attention to the mineral or ash constituents of the plant; and thus anticipate, to a certain extent, the subsequent famous "mineral" theory of the great Liebig. The French chemist maintained that these ash ingredients were essential; and that without them plant-life was impossible. He also adduced fresh experiments of his own in support of the theory, based on the experiments of Bonnet, Priestley, Ingenhousz, and Sénéquier, that plants obtain their carbon from the carbonic acid gas in the air, under the influence of the sunlight. He was of opinion that the *hydrogen* and *oxygen* of the plant were, probably, chiefly derived from water. He showed that by far the largest portion of the plant's substance was derived from the air and from water, and that the ash portion was alone derived from the soil. To Saussure we owe the first definite statement on the different sources of the plant's food. It may be said that the lapse of nearly a century has shown his views to be, in the main, correct.

Source of Plant-nitrogen.

There was one question, which, even at that remote period in the history of the subject, engaged the attention of agricultural chemists—viz., the question of the source of the plant's *nitrogen*—a question which may

be fitly described at the present hour as still the burning question of agricultural chemistry.¹

As soon as it was discovered that nitrogen was a constituent of the plant's substance, speculations as to its source were indulged in. The fact that the air furnished an unlimited storehouse of this valuable element, and the analogy of the absorption of carbon (from the same source by plant-leaves), naturally suggested to the minds of early inquirers that the free nitrogen of the air was the source of the plant's nitrogen. As, however, no direct experiments could be adduced to prove this theory, and as, moreover, nitrogen was found in the soil, and seemed to be a necessary ingredient of all fertile soils, the opinion that the soil was the only source gradually supplanted the older theory. Little value, however, must be attached to these early theories, as they can scarcely be said to have been based on experiments of serious value. Indeed it may be safely affirmed, in the light of subsequent experiments, that it was impossible for this question to be decided at this early period, from the fact that analytical apparatus, of a sufficiently delicate nature, was then wholly unknown. Indeed it is only within the last few years that it has been possible to carry out experiments which may be regarded as at all crucial. A short sketch of the development of our knowledge of the relation of nitrogen to the plant will be given further on.

¹ See p. 40 to 45.

Sir Humphry Davy's Lectures.

A series of lectures on agricultural chemistry, delivered by Sir Humphry Davy during the years 1802-1812, for the Board of Agriculture, and subsequently published in book form in the year 1813,¹ affords us an opportunity of gauging, pretty accurately, the state of knowledge on the subject at the time.

Position of Agricultural Chemistry at beginning of Century.

In his opening lecture Davy says: "Agricultural chemistry has not yet received a regular and systematic form. It has been pursued by competent experimenters for a short time only. The doctrines have not as yet been collected into any elementary treatise, . . . and," he adds, "I am sure you will receive with indulgence the first attempt made in this country to illustrate it by a series of experimental demonstrations."

He further on remarks: "It is evident that the study of agricultural chemistry ought to be commenced by some general inquiries into the composition and nature of material bodies, and the law of their changes. The surface of the earth, the atmosphere, and the water deposited from it, must either together, or separately, afford all the principles concerned in vegeta-

¹ Elements of Agricultural Chemistry, in a course of Lectures for the Board of Agriculture. By Sir Humphry Davy. (London, 1813.)

tion, and it is only by examining the chemical nature of these principles that we are capable of discovering what is the food of plants, and the manner in which this food is supplied and prepared for their nourishment."

Davy goes on further to say: "No general principles can be laid down respecting the comparative merits of the different systems of cultivation and the various systems of crops adopted in different districts, unless the chemical nature of the soil, and the physical circumstances to which it is exposed, are fully known."

He recognises the enormous importance of experiments. "Nothing is more wanting in agriculture than experiments, in which all the circumstances are minutely and scientifically detailed."

In dealing with the composition of plants he says: "It is evident that the most essential vegetable substances consist of hydrogen, carbon, and oxygen, in different proportions, generally alone; but in some few cases combined as carbon and nitrogen. The acids, alkalies, earths, metallic oxides, and saline compounds, though necessary in the vegetable economy, must be considered as of less importance, particularly in their relation to agriculture, than the other principles."

Further on: "It will be asked, Are the pure earths in the soil merely active as mechanical or indirect chemical agents, or do they actually afford food to the plant?"

This question he answers by saying that "water,

and the decomposing animal and vegetable matter existing in the soil, constitute the true nourishment of plants; and as the earthy parts of the soil are useful in retaining water, so as to supply it in the proper proportion to the roots of the vegetables, so they are likewise efficacious in producing the proper distribution of the animal or vegetable matter. When equally mixed with it, they prevent it from decomposing too rapidly; and by their means the soluble parts are supplied in proper proportions."

Value of Davy's Lectures.

The chief value of these lectures is due to the fact that they form the first attempt to connect in a systematic manner the various scattered facts, up to that time ascertained, and to interpret their bearing on agricultural practice. We have in them, it is true, a strange mixture of facts belonging rather to botany and physiology than to agricultural chemistry; still they undoubtedly furnished a great impetus to inquiry, and at the same time they did much to popularise the science.

But not merely did Davy summarise and systematise the various results arrived at by others, he also made many valuable contributions to the science himself. The conclusions he drew from the results he obtained were, no doubt, in many cases false, and in other cases exaggerated; still the results possess a permanent interest. He may be said to have worked

out many of the most important *physical* or *mechanical* properties of a soil, although exaggerating the importance of the influence of these properties on the question of fertility.¹

These experiments had to do with the heat- and water-absorbing powers of a soil. He experimented on a brown fertile soil, and a cold barren clay, and found at what rate they lost heat. "Nothing," he says, "can be more evident than that the genial heat of the soil, particularly in spring, must be of the highest importance to the rising plant; . . . so that the temperature of the surface, when bare and exposed to the rays of the sun, affords at least one indication of the degree of the fertility."

Again he says: "The power of soils to absorb water from air is much connected with fertility. . . . I have compared the absorbent powers of many soils, with respect to atmospheric moisture, and I have always found it greatest in the most fertile soils; so that it affords one method of judging of the productiveness of land."

Where he erred was in overestimating the functions of the mechanical properties of a soil, and in considering fertility to be due to them alone.

During the next thirty years or so, little progress seems to have been made in the way of fresh experimentation.

¹ This department of agricultural research was subsequently carried on by Sprengel, Schübler, and others.

Boussingault.

In 1834, Boussingault,¹ the most distinguished French agricultural chemist of the century, began that series of brilliant chemico-agricultural experiments on his estate at Bechelbronn, in Alsace, the results of which have added so much to agricultural science. It was the first instance of the combination of "science with practice," of the institution of a laboratory on a farm; a combination peculiarly fitted to promote the interests of agricultural science, and an example which has been since followed with such magnificent results in the case of Sir John Lawes's famous Rothamsted Experiment Station, and other less known research stations.

Boussingault's first paper appeared in 1836, and was entitled, "The amount of nitrogen in different kinds of foods, and on the equal value of foods founded on these data."

In the year following other papers were published on such subjects as the amount of gluten in different kinds of wheat; on the meteorological considerations of how far various agricultural operations — such as extensive clearings of wood, the draining of large swamps, &c.—influence of climate on a country; and on experiments on the culture of the vine.

Boussingault was the first observer to study the scientific principles underlying the system of *rotation*

¹ Born in Paris, 1802; died 11th May 1887.

of crops. In 1838 he published the results of some very elaborate experiments he had carried out on this subject. He also was the first chemist to carry out elaborate experiments with a view to deciding the question of the assimilation by plants of free atmospheric nitrogen. His first contribution to the subject was published in 1838, but can scarcely be regarded as possessing much scientific value, except in so far as it stimulated further research. Some thirteen years later he returned to this question; and during the years 1851-1855 carried out most elaborate experiments, the results of which, until quite recently, were generally regarded as having, along with the experiments of Messrs Lawes, Gilbert, and Pugh, definitely settled the question.¹

In 1839 Boussingault was elected a member of the French Institute, an honour paid to him in recognition of his great services to agricultural chemistry.²

¹ See p. 40.

² While much of Boussingault's work was carried out previous to the year 1840, he continued to enrich agricultural chemistry with numerous valuable contributions up till the time of his death. It may be well here to mention the names of his most important contributions to agricultural science, made subsequent to 1840.

In 1843 he published, in a work entitled '*Economie Rurale*,' the results of his numerous experiments and researches. This work is well known to English agriculturists from an English translation which appeared in 1845 (Boussingault's '*Rural Economy*,' translated by G. Law. H. Ballière, London).

In 1860 appeared the first volume of his last great work, '*Agro-nomie Chimie Agricole et Physiologie*.' This work, which consisted of seven volumes, was not finished till 1884. He died on the 11th

The foregoing is a brief epitome of the history of the development of agricultural chemistry up to the year 1840, the year which witnessed the publication of one of the most memorable works on the subject, which has appeared during the present century—Liebig's first report to the British Association, a work which may be described as constituting an epoch in the history of the science. Liebig's position as an agricultural chemist was so prominent, and his influence as a teacher so potent, that a few biographical facts may not be out of place before entering upon an estimate of his work.

Liebig.

Liebig was born at Darmstadt in the year 1803. He was the son of a drysalter, and early devoted himself to the study of chemistry in the only way at first at his disposal—viz., in an apothecary's shop. Soon finding, however, his opportunities of study limited, he left the apothecary's shop for the University of Bonn. He did not remain long at Bonn, but in a short time left that university for Erlangen, where he studied for some years, taking his Ph.D. degree in 1822. His subsequent studies were carried on at Paris under Gay-Lussac, Thénard, Dulong, and other distinguished chemists. Through the influence of A. Humboldt, who was at that time in Paris, and whose acquaintance he was fortunate enough to make, he

of May 1887. It may be added that the Royal Society of London awarded him the Copley medal in 1887.

was received into Gay-Lussac's private laboratory. In 1824—that is, when he was only twenty-one years of age—he was appointed Professor *Extraordinarius* of Chemistry at the University of Giessen. Two years later he was appointed to the post of Professor *Ordinarius*—an appointment which he held for twenty-five years. In 1845 he was created Baron, and in 1852 appointed Professor at Munich. He died in 1873.

His First Report to British Association.

The report above referred to was made by Liebig at the request of the Chemical Section of the British Association. It was read to a meeting of the Association held in Glasgow in 1840, and was subsequently published in book form, under the title of 'Chemistry in its Application to Agriculture and Physiology.'

Liebig's position, past training and experience were such as to peculiarly fit him for the part of pioneer in the new science. As Sir J. H. Gilbert has remarked,¹ "In the treatment of his subject he not only called to his aid the previously existing knowledge directly bearing upon his subject, but he also turned to good account the more recent triumphs of organic chemistry, many of which had been won in his own laboratory."

In his dedication to the British Association at the beginning of the book, Liebig says: "Perfect agriculture is the true foundation of all trade and industry

¹ See British Association Proceedings, 1880, p. 511.

—it is the foundation of the riches of States. But a rational system of agriculture cannot be formed without the application of scientific principles; for such a system must be based on an exact acquaintance with the means of nutrition of vegetables, and with the influence of soils and actions of manure upon them. This knowledge we must seek from chemistry, which teaches the mode of investigating the composition and of studying the characters of the different substances from which plants derive their nourishment."

His criticism of the "Humus" Theory.

The first subject which Liebig discusses is the scientific basis of the so-called "humus" theory. The humus theory seems to have been first promulgated by Einhof and Thaer towards the close of last century. Thaer held that humus was the source of plant-food. He stated in his published writings that the fertility of a soil depended really upon its humus; for this substance, with the exception of water, is the only source of plant-food. De Saussure, however, by his experiments—the results of which he had published in 1804—had shown the fallacy of this humus theory; and his statements had been further developed and substantiated by the investigations of the French chemist Braconnot and the German chemist Sprengel. Despite, however, the experiments of Saussure, Braconnot, and Sprengel, the belief that plants derived the

carbonaceous portion of their substance from humus still seemed to be commonly held in 1840.

While Liebig, therefore, can scarcely be said to have been the first to controvert the humus theory, he certainly dealt it its death-blow. He reasserted de Saussure's conclusions, and by some simple calculations showed very clearly that it was wholly untenable. One of the most striking of the arguments he brought forward was the fact that the humus of the soil itself consisted of the decayed vegetable matter of preceding plants. This being so, how, he asked, could it be the original source of the carbon of plants? To reason thus was simply to reason in a circle. He pointed out, further, that the comparative insolubility of humus in water, or even in alkaline solutions, told against its acceptance as correct.

His Mineral Theory.

Having thus controverted the humus theory, he then goes on to deal with the question of the source of the various plant constituents. In treating of the relation of the soil to the plant, he puts forward his "mineral" theory. It cannot be doubted that, while the advance of science since Liebig's time has induced us to considerably modify his mineral theory, it contained the statement of one of the most important facts in the chemistry of plant physiology. He was the first to fully estimate the enormous importance of the mineral portion of the plant's food, and point the way to one of

the chief sources of a soil's fertility. Up to this period the ash constituents had been generally considered to be of minor importance. By emphasising the contrary opinion, and insisting upon their essentialness to plant-life, he gave to agricultural research a fresh impetus upon the right lines. His statement of his mineral theory was in the main true, but was not the whole truth.

De Saussure, as has already been pointed out, to a certain extent, anticipated Liebig's mineral theory. He was of the opinion that whatever might be the case with some of the mineral constituents of plants, others were necessary, inasmuch as they were always found in the ash. Of these he instanced the alkaline phosphates. "Their small quantity does not indicate their inutility," he sagaciously remarks. Sir Humphry Davy, as has already been pointed out, missed recognising the true importance of the ash constituents. It was left to Liebig, then, to restate the important doctrine of the essentialness of the mineral matter, already implied to some extent by de Saussure.

Liebig says: "Carbonic acid, water, and ammonia are necessary for the existence of plants, because they contain the elements from which their organs are formed; but other substances are likewise necessary for the formation of certain organs destined for special functions, peculiar to each family of plants. Plants obtain these substances from inorganic nature."

While insisting on the importance of the mineral

constituents, he did so in a more or less general way, not sufficiently distinguishing one mineral constituent from another.

As all plants contained certain organic acids, and as these organic acids were nearly always found in a neutral state—*i.e.*, in combination with bases, such as potash, soda, lime, and magnesia—the plant must be in a position to take up sufficient of these alkaline bases to neutralise these acids. Hence the necessity of these mineral constituents in the soil. According to him, however, the exact nature of the bases was a point of not so much importance. He assumed, in short, as has been pointed out by Sir J. H. Gilbert, a greater amount of mutual replaceability amongst the bases than can be now admitted.

Passing on to a consideration of the difference of the mineral composition of different soils, he attributes this to the difference in the rocks forming the soils. “Weathering” is the great agent at work in rendering available the otherwise locked-up stores of fertility. He attributes the benefits of fallow exclusively to the increased supply of these incombustible compounds which were thus rendered available to the plant. Treating of this subject, he says: “From the preceding part of this chapter” (in which he has been explaining weathering) “it will be seen that fallow is that period of culture when the land is exposed to progressive disintegration by the action of the weather, for the purpose of liberating a certain

quantity of alkalies and silica, to be absorbed by future plants."

His Theory of Manures.

Treating of manures, he showed how the most important constituents of manures were *potash* and *phosphates*. In the first edition of his work he also insisted on the value of *nitrogen* in manures, condemning the want of precautions, in the treatment of animal manures, against loss of nitrogen.

In the later editions of his work he seems to have receded from that opinion, and considered that there was no necessity for supplying nitrogen in manures, since the ammonia washed down in rain was a sufficient source of all the nitrogen the plant required. It was here that Liebig went astray, first in denying the importance of supplying nitrogen as a manure; and secondly, in overestimating the amount of ammonia washed down in rain, which has subsequently been shown to be entirely inadequate to supply plants with the whole of their nitrogen.¹

His Theory of Rotation of Crops.

In explaining the benefits of the rotation of crops, Liebig propounded a very ingenious theory, but one

¹ It may be pointed out that, while the amount of ammonia washed down by the rain is small, Schloesing has found in some recent experiments that a damp soil may absorb from the air in the course of a year 38 lb. of combined nitrogen, chiefly ammonia, per acre. See p. 132.

which was largely of a speculative nature, and which has since been shown to be unfounded on any scientific basis. It was to the effect that one kind of crop excreted matters which were especially favourable to another kind of crop. He did not say whether he considered such excretion positively injurious to the crop which excreted them; but he inferred that what was excreted by the crop was what was not required, and what could, therefore, be of little benefit to a crop of the same nature following it.

The second portion of Liebig's report dealt with the processes of fermentation, decay, and putrefaction.

Publication of Liebig's Second Report to British Association.

In 1842 Liebig contributed his second famous report to the British Association, subsequently published under the title of 'Animal Chemistry; or, Organic Chemistry in its Applications to Physiology and Pathology.' The publication of this report created even greater interest than the publication of his first work. In it he may be said to have contributed as much to animal physiology, as, in his first, he did to agricultural chemistry. His subsequent principal works on agricultural chemistry were—'Principles of Agricultural Chemistry,' published in 1855, and 'On Theory and Practice in Agriculture,' 1856.

Liebig's services to Agricultural Chemistry.

An attempt has been made to sketch in the very briefest manner some of the main points in Liebig's teaching, as contained in his famous report to the British Association in 1840. Agricultural chemistry up till that year can scarcely be described as having a distinct existence as a branch of chemistry. Much valuable work, it is true, had already been done, especially by his two great predecessors, de Saussure and Boussingault; but it was, down to the year 1840, a science made up of isolated facts. Liebig's genius formed it into an important branch of chemistry, supplied the necessary connection between the facts, and by a series of brilliant generalisations formed the principles upon which all subsequent advance has been built.

As has already been indicated, Liebig's chief claim to rank as the greatest agricultural chemist of the century does not rest upon the number or value of his actual researches, but on the formative power he exercised in the evolution of the science. His master-mind surveyed the whole field of agricultural chemistry, and saw laws and principles where others saw simply a confusion of isolated, and, in many cases, seemingly contradictory facts.

But great as the direct value of Liebig's work was, it may be questioned whether its indirect value was not even greater. The publication of his famous

work had the effect of giving a general interest to questions which up till then had possessed a special interest, and that for comparatively few. Both on the Continent and in England a very large amount of discussion took place regarding his various theories.

Development of Agricultural Research in Germany.

It was especially in Germany, however, that Liebig's work bore its greatest and most immediate fruit. Thanks to the great chemist, the German Government recognised the importance of forwarding scientific research by State aid. Agricultural Departments were added to some of the universities, largely at State expense, while agricultural research stations were, one after another, instituted in different parts of the country.

The first of the agricultural research stations to be founded was the now famous one of Möckern, near Leipzig. It was instituted in the year 1851. Others followed, until at the present day there are some seventy to eighty of these *Versuchs-Stationen* scattered throughout Germany, all well equipped and doing excellent work. Some idea of the activity of the German stations may be inferred when it is stated that up to the year 1877 the total number of papers embodying the results of their experiments published by them amount to over 2000.¹

¹ The example, set by Germany, has been followed by other countries in which well-equipped research stations now exist. Perhaps

To trace the development of agricultural chemistry, subsequent to Liebig's time, in the way it has been done prior to the year 1840, is no longer possible. This is due to the enormous increase in the number of workers in the field, as also to the overlapping nature of their work, which renders a strict chronological record wellnigh an impossibility. It will be better, therefore, to attempt to give a brief statement of our present knowledge on the subject, naming the chief workers in the various departments of the subject.

The Rothamsted Experiments.

Before doing so, it is fitting that reference should be made to the work and experiments of two living English chemists, who have done much to contribute to our knowledge in every branch of the science—viz., Sir John Lawes, Bart., and Sir J. H. Gilbert, F.R.S.

The fame of the Rothamsted experiments is now world-wide; and no single experiment station has ever produced such an amount of important work as the magnificently equipped research station at Rothamsted. The Rothamsted station may be said to date from 1843, although Sir John Lawes was the most striking example of the rapid development of the means of agricultural research is furnished by the United States of America. At present over fifty agricultural experiment stations, more or less well equipped, exist at present in that country, all liberally supplied by State aid. The earliest to be founded, it may be added, was that at Middletown, Connecticut, the date of its institution being 1875.

engaged in carrying out field experiments for ten years previous to that date.¹ In 1843 Sir John Lawes associated with himself the distinguished chemist Sir J. H. Gilbert, and the numerous papers since published have almost invariably borne the two names. The expense of working the station has been borne entirely by Sir John Lawes himself; who has further set aside a sum of £100,000, the Laboratory, and certain areas of land, for the continuance of the investigations after his death. The fields under experimentation amount to about fifty acres. By a Trust-deed, which was signed on February 14, 1889, Sir John Lawes has made over the Rothamsted Experimental Station to the English nation, to be managed by trustees.

It is impossible to enter, in any detail, into the nature and scope of the Rothamsted experiments.² It may be stated that, since the year 1847, some eighty papers have been published on field experiments, and experiments on vegetation; while thirty papers have been published recording experiments on the feeding of animals.³

¹ It may thus claim to be the second oldest experimental station, that instituted by Boussingault at Bechelbronn in Alsace being the oldest.

² For an account of the Rothamsted experiments, and a short biography of Sir John Lawes, the reader is referred to a pamphlet by the present writer, entitled 'Sir J. B. Lawes, Bart., LL.D., F.R.S., and the Rothamsted Experiments' ('Scottish Farmer' Office, 93 Hope Street, Glasgow).

³ Of these numerous elaborate experiments, perhaps those which have attracted the most widespread interest amongst agriculturists

What has all along characterised these valuable experiments has been their practical nature. While their aim has been entirely scientific, the scale of the experiments and the conditions under which they have been carried out, have been such as to render them essentially *technical* experiments. For this reason their results possess, and will always possess, a peculiar interest for every practical farmer.

The greatest services the Rothamsted experiments have rendered agricultural chemistry have been the valuable contributions they have made to our knowledge of the function of nitrogen in agriculture; its relation in its different chemical forms to plant-life; and the sources of the nitrogen found in plants. Researches of a most elaborate nature have been carried out on what is still one of the most keenly debated questions of the present hour—viz., the relation of the “free” nitrogen in the atmosphere to the plant. Of the very highest value also have been the elaborate researches of Mr R. Warington, F.R.S., on the important question of *Nitrification*, which have been in course in the Rothamsted Laboratory for the last fifteen years, and to which full reference will be made in the chapter on Nitrification.

To the Rothamsted experiments also we owe the have been those carried out on the growth of wheat on the same land year after year for a period of nearly fifty years. The important light which this series of experiments has thrown upon the theory of the rotation of crops, and the subject of the manuring of cereals, is very great.

refutation of Liebig's mineral theory. In fact it may safely be said that no experimenters in the field of agricultural chemistry have made more numerous or valuable contributions to the science than these illustrious investigators.

Review of our present Knowledge of Agricultural Chemistry.

Some attempt may now be made to indicate briefly our present knowledge of the more important facts regarding plant physiology, agronomy, and manuring.

Proximate Composition of the Plant.

The great advance made in the direction of the improvement of the accuracy of old analytical processes and the discovery of numerous new ones have furnished us with elaborate analyses of the composition of plants. We now know that the plant-substance is made up of a large number of complex organic substances, formed out of carbon, hydrogen, oxygen, and nitrogen,¹ and that these substances form, on an average, about 95 per cent of the dry vegetable matter; the other 5 per cent being made up of mineral substances. As to the source of these different substances, our knowledge is, on the whole, pretty complete. With regard to the carbon of green-leaved plants, which amounts to from 40 to 50 per cent, subsequent research has confirmed S  n  bier and de

¹ Associated in some cases with phosphorus and sulphur.

Saussure's conclusions, that its source is the carbonic acid gas of the air. The decomposition of the carbonic acid gas is effected by the leaves under the influence of sunlight. That a certain quantity of carbon may be obtained from the carbonic acid absorbed by plant-roots, is indeed probable. Especially during the early stages of plant-growth this source of carbon may be of considerable importance. Generally speaking, however, it may be said of all green-leaved plants, that the chief source of their carbon is the carbonic acid gas in the atmosphere.

Carbon Fixation by Plants.

The exact way in which this decomposition of carbonic acid gas is effected by the leaves is not yet clear. It seems to be directly dependent, in some way or other, on the chlorophyll, or green colouring matter. This decomposition of carbonic acid, and the fixation of the carbon by the plant with the formation of starch, takes place only under the influence of sunlight. During the night a reflex action takes place, which is commonly known as *respiration*, and which is exactly analogous to animal respiration.¹ The rate at which the fixation of carbon takes place depends on the strength of the sun's rays. It seems to take

¹ It must be pointed out that plant-respiration does not take place *only* during the night-time. It probably goes on at all times, but it is only during the night-time that its action is apparent, as the reverse process of carbon assimilation, which goes on at an incomparably greater rate, masks its action during the daytime.

place very rapidly under a strong tropical sun.¹ The action of sunlight on the absorption of carbon has been studied by a number of observers, among others by Sachs, Draper, Cloez, Gratiolet, Caillet, Prillieux, Lommel, &c.

Action of Light on Plant-growth.

Experiments made by several observers, more especially Pfeffer, have shown that the yellow rays of the solar spectrum are the most potent in inducing this decomposition.

Some interesting experiments have been carried out by different observers on the possibility of growing plants under the influence of artificial light. While it would seem that the light from oil-lamps or gaslight is unable to promote growth, except in very exceptional cases, the electric light, or other strong artificial light, seems to be capable of taking the place of sunlight. Heinrich was the first to show that sunlight could be replaced by the magnesium light.

Experiments with the electric light have been carried out by Hervé-Mangon in France and Dr Siemens in England. The plants grown under the influence of the electric light were observed to be of a lighter green colour than those grown under normal conditions, thus indicating a feebler growth; in fact,

¹ The length of the day has an important influence on plant-growth, as is evidenced by the rapid growth of vegetation in Norway and Sweden. In these countries there is a late spring, and a short and by no means hot summer, but a very long period of daylight.

Siemens was of the opinion that the electric light was about half as effective as daylight.¹

These experiments are interesting from an industrial point of view; for it is conceivable that at some distant time electricity might be called to the aid of the agriculturist.

Source of Plants' Oxygen.

With regard to the source of the oxygen, which, next to carbon, is the element most largely present in the plant's substance—amounting to, roughly speaking, about 40 per cent—all evidence seems to indicate that it is chiefly derived from water, which is also the source of the plant's hydrogen. In addition to water, carbonic acid and nitric acid may also furnish small quantities. It has been pretty conclusively proved that the atmospheric oxygen, while necessary to plant-growth, and promoting the various chemical vital processes, is not a direct source of the plant's oxygen. The important function played by atmospheric oxygen in certain stages of the plant's growth has been long recognised. Malpighi, nearly two hundred years ago, observed that for the process of germination atmospheric air was necessary; and shortly after the discovery of the composition of the air was made, oxygen was identified as the important gas in promoting this

¹ A point of great interest which these experiments elucidated is that nocturnal repose is not absolutely necessary for the growth and development of all plants.

process. Oxygen is also especially necessary during the period of ripening.

Source of Plants' Hydrogen.

Hydrogen, which amounts to about 6 per cent, is, as has already been pointed out, chiefly derived from water. It is possible that ammonia also may form a source.

Source of Plants' Nitrogen.

When we come to treat of the source of the nitrogen, which is found in the plant's substance to an extent varying from a fraction of a per cent to about 4 per cent, we enter on a much more debated question.

What is the source, or, what are the sources, of plant-nitrogen? is a question to the solution of which more time and more research have been devoted than to the solution of any other question connected with agricultural chemistry.

The most obvious source is the free nitrogen, which forms four-fifths of the atmospheric air. Reference has already been made to this question.¹ Priestley was the first of the long list of experimenters on this interesting question.

As far back as 1771 he affirmed that certain plants had the power of absorbing free nitrogen; and this opinion he supported by the results of certain experi-

¹ See pp. 15 and 22.

ments he had made on the subject. Eight years later,—viz., in 1779—Ingenhousz further supported this conclusion, and stated that all plants could absorb, within the space of a few hours, noticeable quantities of nitrogen gas. The first to oppose this theory was de Saussure, who, in 1804, carried out experiments which showed that plants were unable to utilise free nitrogen.

Subsequent experiments, carried out by Woodhouse and Sénéquier, supported de Saussure's conclusions. Mention has already been made of Boussingault's elaborate researches on the subject.¹ His first experiments were carried out in 1838. He concluded that plants did not absorb free nitrogen. Georges Ville was the first to reassert the older theory, put forward by Priestley and Ingenhousz. His opinion was founded on experiments he had carried out during the years 1849-52. The subject created so much interest at the time, that a committee of the French Academy—consisting of Dumas, Regnault, Péligot, Chevreul, and Decaisne—were appointed to investigate Ville's experiments. The result of the investigation of the Commission was to confirm Ville's experiments. It is a significant fact, however, that the plant experimented with by the Commission was *cress—a non-leguminous plant*. It has been commonly assumed that the results of recent experiments have confirmed Ville's experiments. It is only proper to

¹ See p. 22.

point out that this is not a necessary inference. The assimilation of free nitrogen by the *leguminosæ*, so far as modern research has revealed, only takes place under the influence of micro-organic life. Ville's experiments, however, were supposed to be conducted under *sterilised* conditions.

In the meantime the results of Boussingault's second series of experiments, carried out between the years 1851 and 1855, were published, and confirmed his earlier experiments.

The results of a large number of experiments subsequently carried out were in support of Boussingault's conclusions. Among them may be mentioned Mène, Harting, Gunning, Lawes, Gilbert and Pugh, Roy, Petzholdt, and Bretschneider.

Such an amount of overwhelming evidence might naturally have been regarded as conclusively proving that the free nitrogen of the air is not an available source of nitrogen to the plant. The question, however, was not decided. In 1876 Berthelot reopened it. From experiments he had carried out, he concluded that free nitrogen was fixed by various organic compounds, under the influence of silent electric discharges. In 1885 he carried out further experiments, from which he concluded that argillaceous soils had the power of fixing the free nitrogen of the atmosphere. This they effected, he was of opinion, through the agency of micro-organisms. Schloesing has recently shown that this fixation of free nitrogen

by soils is extremely doubtful.¹ The gain of nitrogen observed under such conditions can be explained by the absorption by the soil of combined nitrogen—viz., ammonia—from the air.

Berthelot's early experiments in 1876 had the effect of stimulating a number of other experiments, with the result that we now possess the solution of this long-debated and most important problem.

The names of the better known investigators on this subject, in addition to Berthelot's, are those of Hellriegel, Wilfarth, Dehérain, Joulie, Dietzell, Frank, Emil von Wolff, Atwater, Woods, Nobbe, Ward, Breal, Boussingault, Wagner, Schultz-Lupitz, Fleischer, Pagnoul, Schloesing, Laurent, Petermann, Pradınowsky, Beyrenick, Lawes, and Gilbert.

It is impossible to enter into the details of these most important experiments. An attempt may be made, instead, briefly to epitomise them.

Recent Experiments on Nitrogen question.

In the first place, it may be asked, How is it possible that the previous elaborate experiments, published prior to 1876, should now prove unreliable? A satisfactory explanation may be found in the fact, as Lawes and Gilbert have recently pointed out, that the fixation of the free nitrogen by the plant, or within the soil, takes place, if at all, through the agency of electricity or of micro-organisms, or of both.

¹ See Chapter III., pp. 120 and 131.

The earlier experiments, however, were so arranged as to exclude the influence of either of those agencies.

The question has further been limited in its scope. It is now supposed that only plants of the *leguminous* order have the power of drawing upon the free atmospheric nitrogen. Of the experiments above referred to, those of Hellriegel and Willarth are the most striking and important. They found in their experiments, that while the legumes have the power of obtaining their nitrogen from the air, cereals have not. Similar experiments by Atwater in America, and others, support this conclusion.

Their conclusions may be briefly epitomised as follows:—

(a) That the leguminous plants—such as peas, &c.—have the power of drawing their nitrogen supplies from the free nitrogen of the air in a way not possessed by other plants; and that they thus possess two sources of nitrogen—the soil and the air.

(b) That this absorption of free nitrogen is not effected directly by the plant, but is the result, so to speak, of the joint action of certain micro-organisms present in certain soils and in the plant itself, (*symbiosis*).

(c) That this fixation is connected with the formation of minute tubercles on the roots of the plants of the leguminous class; and that these tubercles may be the home of the fixing organism.

(*d*) That these fixing micro - organisms are not present in all soils.¹

While the relation of free nitrogen to the plant has long been, and still is, a very obscure problem, it was early recognised that the combined nitrogen present in soils and manures was an important source of plant-food. Reference has already been made to the early theory of Sir Kenelm Digby regarding the value of nitrates.² De Saussure, as we have also already seen, was fully impressed with the importance of applying nitrogen to the soil as a manure. Liebig's early attitude on this question was to the effect, that to apply nitrogen in manures was quite unnecessary, as the plant had a sufficient source in the ammonia present in the air, which he erroneously supposed was sufficient in quantity to supply all the needs of the crops. Despite this early recognition of the value of combined nitrogen to the plant, it is only of recent years that we have obtained any definite knowledge as to the respective value of its different compounds as manures, or as to the form in which it is assimilated by the plant. It exists in three forms—(1) as organic nitrogen; (2) as ammonia salts; (3) as nitrates and nitrites. Much experimental work has during late years been devoted to studying the comparative action and merits of these three forms.

¹ Further reference is made to this subject in Chapter III., p. 136.

² See p. 6.

Relation of Organic Nitrogen to the Plant.

First, as to the relation of organic nitrogen to the plant. There is a large number of different organic compounds which contain nitrogen. That the plant is able to assimilate certain of these organic compounds, seems, from several experiments, to be extremely probable. From certain researches, carried out as far back as the year 1857, Sir Charles Cameron concluded that the plant could assimilate one of them—viz., *urea*. From what, however, we have subsequently learned regarding the process of “nitrification,” it is quite probable that the nitrogen in these experiments was first converted into nitrates before being assimilated. At any rate, as the plants were not tested for *urea*, the experiments must be regarded as leaving the problem unsolved.

Other experiments were carried out of a similar nature by Professor S. W. Johnson, the different kinds of nitrogen experimented with being *uric acid*, *hippuric acid*, and *guanine*. But here, again, no definite conclusion can be drawn, as no analyses were made of the plants. More recently, however, Dr Hampe has carried out experiments with *urea*, *uric acid*, *hippuric acid*, and *glycocoll*. These experiments may be held as demonstrating the fact that at least one organic compound of nitrogen is capable of being assimilated, as *urea* was actually identified as being present in the plants experimented with. From further experiments,

carried out by Dr Paul Wagner and Wolff, *glycin*, *tyrosin*, and *kreatin* are able to be assimilated by the plant.

Plants able to absorb certain Forms of Organic Nitrogen.

We may conclude, then, from these interesting experiments, that plants are able to absorb certain organic forms of nitrogen. That they do so in nature to any extent is extremely improbable, such organic forms of nitrogen being rarely present in the soil, or if present, being converted into ammonia or nitrate salts before assimilation.

Nature of Humus in the Soil.

While on the subject of organic nitrogen, reference may be briefly made to that substance known as *humus*,—the name applied to the organic portion of soils,—a substance which figures so largely in early theories of plant-nutrition. The most elaborate investigation of the composition of humus has been carried out by Mulder. According to Mulder, it is composed of a number of organic bodies, and he has identified the following substances—ulmin, humin, ulmic, humic, geic acids, &c. These bodies are composed of carbon, hydrogen, and oxygen, which are invariably associated with nitrogen. Detmer and Simon have further investigated the subject. The true function of humus, it would seem, in addition to its numerous mechanical properties, is to furnish, by

its decomposition, carbonic acid and nitrogen—in the form of ammonia and nitric acid—to the soil; the former acting as a solvent of the mineral food, the latter as the source of the plant's nitrogen. The old theory, therefore, that the presence of humus in a soil is a condition of fertility, is not so far removed from the truth. Where there is an abundance of humus in the soil there is likely also to be an abundance of nitrogen.

Relation of Ammonia to the Plant.

It seems to be beyond doubt that nitrogen is directly absorbed by plants in the form of ammonia. Liebig, as we have seen, concluded that this was the great source of nitrogen for the plant, and that the ammonia compounds present in the air were an all-sufficient supply. Subsequent research, while confirming his belief so far as regards the capability of plants to assimilate nitrogen in the form of ammonia, has proved that the amount of ammonia present in the air is very minute, and utterly inadequate to supply the plant with the whole of its nitrogen. Investigations have been made on this subject by Graeger, Fresenius, Pierre, Bineau, and Ville. According to Ville's researches, which are among the most recent, the amount does not exceed 30 *parts per thousand million parts of air*.¹ Some conception

¹ See Phil. Trans., Part II., 1861, pp. 444-446. Lawes & Gilbert. Schloesing has found in the air in the neighbourhood of Paris 1 lb.

of the value of this source of nitrogen may be gained by estimating the quantity falling, dissolved in rain, on an acre of soil throughout the year. Various estimations of the total amount of combined nitrogen, which is in this way brought to the soil, have been made. A certain amount of discrepancy, it is true, is to be found in these various estimations, no doubt largely due to the difference in the circumstances under which the investigations were carried out. Mr Warington has made several investigations at Rothamsted, and, according to his most recently published figures, the total quantity only amounts to 3.37 lb. per acre per annum—of which only 2.53 lb. is as ammonia itself.¹

As already mentioned, there can be little doubt that plants can absorb nitrogen in the form of ammonia. The question of how far plant-leaves are able to absorb ammonia is a much debated one. It is probable that if they can do so, it is only to a very small extent.² The question as to whether the plant's roots can absorb ammonia or not, is also a very keenly debated one. The point is a very

of ammonia in 26,000,000 cubic yards; while Müntz found only about half that amount in a similar quantity of air on the top of the Pic du Midi.

¹ See Chapter III., pp. 119, 120; Appendix, p. 155.

² Some recent experiments by Dyer and Smetham would seem to show that comparatively small quantities of ammonia in the air prove actually hurtful to plant-life. Thus they found that one volume of ammonia in 1000 volumes of air was fatal to hardy plants; while one volume in 3000 volumes killed tender ones.

difficult one to decide, and is much complicated by the consideration that ammonia, when applied to the soil, is so speedily converted into nitric acid. Despite, however, these difficulties, and the vast amount of controversy on the point, the experiments of Ville, Hosäus and Lehmann, seem to indicate beyond doubt that ammonia is a direct source of nitrogen. Lehmann's experiments would seem, further, to indicate that there are certain periods of a plant's growth when its preference for ammonia salts seems to be greater than at other times. The point, however, it must be confessed, is still an obscure one. The great difficulty in deciding it, as has just been said, lies in the fact that ammonia salts, when applied to a soil, are, by the process of nitrification, converted into nitrates. In experimenting, therefore, with ammonia, and noting the results, it is wellnigh impossible to say, except by subsequent analyses, whether the nitrogen in the ammonia salts has not been converted into nitrates before assimilation.

Relation of Nitric Acid to the Plant.

Thirdly, as to nitrogen in the form of nitrates. While it is true that plants can absorb nitrogen in certain organic forms and as ammonia salts, it is now a well-known fact that the chief, and by far the most important, source of nitrogen is nitric acid. Probably more than 90 per cent of the nitrogen absorbed by

green-leaved plants from the soil is absorbed as nitrates. The tendency of all nitrogen compounds in the soil is towards conversion into nitric acid. It is the final form of nitrogen in the soil. The precise method in which this conversion takes place is a discovery of only a few years' standing. The great economic importance of this discovery, made by the French chemists Schloesing and Müntz, and associated in this country with the names of Warington, Munro, and P. F. Frankland, is only gradually being appreciated. It is without doubt one of the most interesting made in the domain of agricultural chemistry of late years.

Nitrification.

It was in the year 1877 that the two French chemists above referred to published the results of some experiments they had carried out, which proved that nitrification—the name given to the process by which ammonia or other nitrogen salts are converted in the soil into nitric acid—was due to the action of micro-organic life.

The basis of the theory rests upon the fact that dilute solutions of ammonia salts or urine, containing all the necessary constituents of plant-food, if previously sterilised, may be kept for an indefinitely long period of time, provided the air supplied be filtered through cotton wool,—so as to prevent the entrance of micro-organisms—without any formation of nitrates.

Introduce, however, into such a solution a little fresh soil, and nitrification will soon follow.

The conditions under which the nitrification ferment acts, as well as the nature of the ferment, or rather ferments, have subsequently been carefully studied by Schloesing and Müntz, Winogradsky, Dehérain, Kellner, and other Continental observers, and especially by Warington, Munro, and P. F. Frankland in this country. These conditions cannot be gone into here. They will be fully discussed in the chapter on Nitrification. Briefly stated, they are a certain range of temperature (between slightly above freezing-point and 50° C., the maximum activity taking place, according to Schloesing and Müntz, at about 30° C.); a plentiful supply of atmosphere oxygen (hence the fact observed by Warington, that nitrification is chiefly limited to the surface-soil); a certain amount of moisture; and the presence of certain of the necessary mineral plant constituents, and the presence of carbonate of lime.

The light which these discoveries throw upon the extremely complicated question of the fertility of the soil is considerable, as it follows that no soil can be regarded as really a fertile one in which the process of nitrification does not freely take place. They furthermore explain many facts, hitherto observed but not well understood, with regard to the action of different nitrogenous manures.

Ash Constituents of the Plant.

We now come to consider the present state of our knowledge on the essentialness of the ash or mineral portion of the plant. While a portion of the plant's substance which, up to Liebig's time, had obtained little notice, it has, since the publication of his famous "mineral" theory, obtained an ever-increasing amount of investigation.

Up till 1800 practically nothing was known of the function of the ash constituents. In 1802 de Saussure wrote that it was unknown whether the constituents of many plants were due to the soils on which they grew, or whether they were the products of vegetable growth. Some two years later, however, he was enabled to carry out a number of experiments which really placed the subject on a firm scientific basis. The essentialness of the ash constituents was only, however, placed beyond all doubt by Wiegmann and Polstorff's researches, carried out in 1840.

Reference has already been made to the great stimulus given to research by the promulgation of Liebig's mineral theory.

Methods of Research.

In epitomising the vast amount of work carried on since 1840, with the view of ascertaining the essentialness of the various substances found in the ash of plants, two methods of experimentation have been followed.

Artificial Soils.

The first of these two methods was that adopted in the famous experiments, carried out by Prince Salm-Horstmar, which have done so much to further our knowledge on this question. It consisted in growing plants on an artificial soil—formed out of sugar-charcoal, pulverised quartz or purified sand—to which were added the different food constituents.

Water-culture.

While the results obtained by Prince Salm-Horstmar by this method were of a most valuable nature, subsequent experimenters have abandoned his method for the other method—viz., “water-culture.” The medium used in this process is pure water; and it is from experiments carried out in water-culture that much of our present knowledge, in regard to the relation of the ash constituents to the plant, is due.

The names of those who have worked in this department are very numerous. Among them may be mentioned Knop, Sachs, Stohmann, Nobbe, Rautenberg, Kühn, Lucanus, W. Wolff, Hampe, Beyer, E. Wolff, P. Wagner, Bretschneider and Lehmann. The results obtained by these and other experimenters have demonstrated the following facts.

The substances which have been found in the ash of plants are: *potash, soda, lime, magnesia, oxide of iron, oxide of manganese, phosphoric acid, sulphuric acid,*

silica, carbonic acid, chlorine, lithia, rubidia, alumina, oxide of copper, bromine, iodine, and occasionally even other substances. Of these, however, only six are probably absolutely necessary for plant-growth—viz., *potash, lime, magnesia, oxide of iron, phosphoric acid, and sulphuric acid*. Three other substances seem also to be almost invariably present, and may possibly be essential—in very minute quantities at any rate—viz., *chlorine, soda, and silica*. With regard to *alumina* and *oxide of copper*, these constituents must be regarded as accidental; while *iodine* and *bromine* only occur in the ash of marine plants.

Method of Absorption of Plant-food.

A department of vegetable physiology which has had much work devoted to it is the method in which plant-roots absorb their food. The plant's nourishment is absorbed in solution by means of the roots. Its absorption takes place, according to Fischer and Dutrochet, who have investigated the subject at great length, by the process known as *endosmosis*. It has also been established by numerous experiments, that different plants require different constituents in different proportions.

Water as a Carrier of Plant-food.

The function performed by water, as the carrier of plant-food, and the motion of the sap of the plant, are questions which have also received much atten-

tion. The motion of the plant's sap seems to have attracted a great deal of attention at a very early stage of the study of plant physiology. As far back as 1679, Marriotte studied it. Among other old experimenters were Hales, Guettard, Sénécier, Saint-Martin, de Candolle, and Miguel. In more recent times, it has been investigated by Schübler, Lawes and Gilbert, Knop, Sachs, Unger, and Hosäus. Some idea of the enormous amount of water transpired by plant-leaves may be gained by the statement that from 233 lb. to 912 lb. of water are transpired for every pound of plant-tissue formed.¹

Agronomy.

When we come to deal with questions relating to the chemistry of the soil, we find that so much investigation has been devoted to this one branch of agricultural chemistry as to constitute it a special branch by itself—known in France under the name of *agronomie*—and being taught in the large agricultural colleges by special professors of the subject. The value of studying the properties of soils was recognised at an early period. This study was for long largely confined to their *physical*, or, what are popularly known as their *mechanical* properties. Thus

¹ According to the experiments of Hellriegel and Wollny. The quantity, it may be added, varies with the leaf-surface and the length of the period of growth of the plant. It is greatest with clovers and grasses, and least in the potatoes and roots.

Sir Humphry Davy ascertained many important facts with regard to the heat and water absorbing and retaining properties of soils.

Retention by Soil of Plant-food.

It was not till a later period that the power soils possess of fixing from their watery solutions various plant-foods, both organic and inorganic, was discovered. The earliest recognition of this most important property of soils was made by Gazzeri, who, in 1819, called attention to the fact that the dark fluid portion of farmyard manure was purified on passing through clay. He concluded that soils, more especially clayey soils, possessed the property of being able to fix from their watery solutions the necessary plant-food constituents, and fix them beyond risk of loss, only affording a gradual supply to the plant as required.

The first experiments carried out on this subject were those by Huxtable and Thompson in 1850. The liquid portion of farmyard manure was filtered through soil and subsequently examined, when it was found to have not only lost its colour, but also to have lost its smell. Ammonia and ammonia salts were also experimented with, and it was found that soils possessed the power of fixing ammonia.

To Thomas Way, however, we are indebted for the most valuable contribution on this important subject made by any one single investigator. His experiments were not merely carried out with regard

to ammonia, but also with regard to other bases—such as potash, lime, magnesia, soda, &c. Since Way's experiments much work has been done by Liebig, Stohmann, Henneberg, and Heiden, as also by Voelcker, Eichorn, Knop, Rautenberg, Pochwissnew, Warington, Beyer, Bretschneider, Sestini, Laszkowsky, Strehl, Pillnitz, Peters, W. Wolff, Lehmann, and Biedermann.

Bases and Acids fixed by Soil.

From these experiments it may be taken as proved beyond doubt that soils have the power of fixing, to a greater or less extent, the following bases: ammonia, potash, lime, magnesia and soda; as well as the two acids, phosphoric and silicic. The order in which the different bases are fixed is an important point. It would seem that the soil has a greater affinity for the more valuable manurial substances, such as ammonia, potash, and lime, and that these substances are first fixed. That in fixing any one of the above-mentioned bases from its solution, it can only do so at the expense of another base. Thus, in fixing potash, either lime, magnesia, or soda must be given up. Further, when a base in solution, as sulphate or chloride, is absorbed by a soil, the base is alone fixed, while the sulphuric acid or chlorine is left in solution. Lastly, the amount of base absorbed by a soil depends on the concentration of its solution, on the nature of its combination, and the temperature.

Way found in his experiments that a clay soil has more power than a peaty soil, and that a peaty soil has more power than a sandy soil.

Causes of this Fixation.

So much for the fact of soil absorption; as to the cause or causes of this absorption, a great number of theories have been put forward. Those may be divided into two classes—those accounting for it as due to physical properties of the soil; and those, on the other hand, explaining it as due to chemical action.

To the latter class Way's belonged. He explained it as due to the formation in the soil of hydrated double silicates, consisting of a silicate of alumina, along with a silicate of the base fixed. Brüstlein and Peters, on the other hand, were of the opinion that it was purely physical in its nature. A theory has been advanced that it is due to the formation of insoluble ulmates and humates, formed by the union of ulmic and humic acids, along with the bases fixed. Among others who devoted investigation to this interesting question, may be mentioned Rautenberg and Heiden.

On reviewing the evidence, it seems to be pretty well established that it really is mainly a chemical act, due chiefly to the formation of double silicates, and doubtless to a certain extent to the formation of insoluble humates and ulmates. Heiden's ex-

periments would seem to indicate, however, that it is also partly of a physical nature.

With regard to the absorption of phosphoric acid, this has been shown to be a chemical act, and depends on the formation of insoluble phosphates of calcium, iron, aluminium, and magnesium, the percentage of iron especially determining this.

Much analytical work has been accomplished of late years with a view of ascertaining the amount of ash in different kinds of plants, and in the different parts of the plant.

Action of Manures.

The department of agricultural chemistry which has been most largely developed of late years is that connected with the problems of *manuring*. It is, from a practical point of view, of most value. It is some considerable time since we have recognised that the only three ingredients it is, as a rule, expedient to apply as artificial manures, are *nitrogen*, *phosphoric acid*, and *potash*. The nature, mode of action of the different compounds, and properties of these three substances, and their comparative influence in fostering plant-growth, together with the economic question of which form is, under various circumstances, the most economical for the farmer to use, have together given rise to a large number of "field" and "pot" experiments. As the principles underlying this prac-

tice form the subject of the following treatise, any further discussion of the question must be left to the following chapters.

Note.—The reader interested in the historical development of agricultural chemistry is referred to Sir J. H. Gilbert's Presidential Address to the Chemical Section of the British Association, 1880.

PART II.

PRINCIPLES OF MANURING

CHAPTER I.

FERTILITY OF THE SOIL.

IT is necessary to clearly understand to what the fertility of a soil is due ere we can hope to master the theory of manuring.

What constitutes Fertility in a Soil.

The question, What constitutes fertility in a soil? is by no means an easy one to answer. If we say, The presence of a plentiful supply of the constituents which form the plant's food, our answer will be incomplete. Similarly, if we reply, A certain physical condition of the soil—here, again, it will be found equally unsatisfactory; for fertility of a soil depends both on its physical condition and on its chemical composition, and indeed even on other circumstances. It may be well, then, before proceeding to treat of the nature and action of the different manures, to offer a brief statement of the conditions of fertility so far, at any rate, as we at present know

them. For it may be well to warn the reader that, despite the great amount of work carried out on this subject by experimenters, we still have much to learn before we shall be in a position fully and clearly to understand the subject of soil-fertility in all its bearings.

Apart altogether from the influence exerted by climate, latitude, altitude, and exposure, the fertility of a soil may be said to depend on the following properties. These we may divide into three groups or classes:—

1. Physical or mechanical.
2. Chemical.
3. Biological.

I. Physical Properties of a Soil.—The physical properties of a soil are generally admitted to have a very important bearing on its fertility. This has been long practically recognised, and perhaps has in the past been unduly exalted in importance, at the expense of the no less important functions of the chemical.¹ The reason of this is doubtless to be ascribed to the fact

¹ This statement perhaps needs qualification. While the important rôle played by the physical qualities of the soil were in the early years of the science recognised, of more recent years the chemical composition of the soil has been engaging almost exclusive investigation. Physical properties of the soil have recently acquired a further importance in the eyes of the agricultural chemist, from the important influence they exert on what we have here called the biological properties of a soil—viz., the development of those fermentative processes whereby plant-food is prepared to a large extent.

that it is much easier to study the physical properties of a soil than it is to study the chemical; and that, while we are in possession of a very large amount of useful information with regard to the former, we are at present only on the threshold of our knowledge of the latter.

Variety of Soils.

It is a matter of common observation that soils differ widely in their mechanical nature. The early recognition of this fact is evidenced by the large number of technical terms which have been long in vogue among farmers descriptive of these differences. Thus soils are in the habit of being described as “heavy,” “light,” “stiff,” “strong,” “warm,” “cold,” “wet,” “damp,” “peaty,” “clayey,” “sandy,” “loamy,” &c., &c.

Absorptive Power for Water.

One of the most important of the physical properties of a soil is its power to absorb water.

Water to the plant economy is just as important and necessary as it is to the animal economy. Consequently it is of primary importance to examine into the conditions which regulate the absorption of this important plant-food by the soil.

By the absorptive power of a soil is meant its capacity for drinking in any water with which its particles may come in contact. This power depends, first, on the predominance of its proximate constituents—viz.,

sand, clay, carbonate of lime, and humus; and secondly, on the fineness of the soil-particles.

Absorptive Power of Sand, Clay, Humus.

First, then, with regard to the absorptive power of sand, clay, and humus. Of these, sand possesses this power to the least extent, clay to a greater extent, while humus possesses it most of all.¹

The extent, therefore, of the absorptive power of a soil depends very much on the proportions in which it possesses these three ingredients. The more sandy a soil is, the less will its power be of absorbing water; and this, there is little doubt, is one of the reasons why a sandy soil is, as a rule, an unfertile soil. Of course there are other and even more important reasons; but that this absorptive power has an important bearing on the question is conclusively proved by the fact that sandy soils are more fertile in a climate where rain is frequent than in one where much dry weather prevails. The incapacity of a sandy soil to absorb a large quantity of moisture is not fraught with such evil effects to the crops in the former case, because it is counteracted by the climatic conditions, which obviate the necessity, in a soil, of possessing great absorptive powers.

¹ A good example of the absorptive capacity of a soil containing a large quantity of vegetable matter is furnished by peat-bogs, which, sponge-like, can absorb enormous quantities of water. (See Appendix, Note I., p. 98.)

The converse, of course, we may mention in passing, holds good of clayey soils.

Fineness of Soil-particles.

The second quality in a soil on which its absorptive power depends is the fineness of its particles. The great benefit which a soil derives from a good tilth, in this respect, was one of the reasons why Tull's system of horse-hoeing husbandry was so successful in its results.¹ The finer the soil-particles, it may be said generally, the greater is the absorptive power of the soil.

Limit to Fineness.

There is, however, a limit to the fineness to which the particles of a soil ought to be reduced; for it has been found by experiment that when a certain degree of fineness is reached, the absorptive power decreases with any further pulverisation. A German experimenter found, for example, that a garden loam, capable of absorbing 114 per cent of water in its natural state, when pulverised very fine was able to absorb only 62 per cent of water. Here, clearly, the limit

¹ Jethro Tull, an early well-known agricultural writer, who lived about the middle of last century, propounded the theory, that as the food of plants consisted of the minute earthy particles of the soil, all that was required by the skilful farmer was to see that his soil was properly tilled. He accordingly published a work entitled 'Horse-hoeing Husbandry,' in which he advocated a system of thorough tillage. (See Historical Introduction, p. 10.)

to which it is advisable to pulverise a soil had been exceeded.

Reason of the above.

It is not difficult to see why this should be so. The amount of water that a soil can soak up is due to the number of pores, or air-spaces, it contains of a certain size. If these pores are large and few in number, the amount of water absorbed will be naturally less than when they are numerous and smaller in size. Up to a certain extent, the more a soil is broken the greater will be the number of pores created, of a size to permit the water to soak in. Beyond that point the pores become too minute, and the soil becomes too compact, each particle clinging together too closely.

Retentive Power of Soils for Water.

Now closely connected with this absorptive power of soils, which we have just been considering, is the power soils possess of holding or retaining the water they absorb. This power, it will be seen at a glance, must have an important bearing on the fertility of a soil.

Importance of Retentive Power.

As a considerable interval often elapses between the periods of rainfall, soils, if they are to support vegetable growth, must be able to store up their water-supply against periods of drought. This is

all the more necessary when we remember that, in the case of heavy crops, the rainfall would often be inadequate to supply the water necessary for their growth. In fact, it has been estimated that the average evaporation from soils bare of any cultivation is equal to the rainfall. That the evaporation from soils covered with vegetation is very much greater, has been strikingly shown by a calculation made by the late eminent American botanist, Professor Asa Gray, who calculated that a certain elm-tree offered a leaf-surface, from which active transpiration constantly went on, of some five acres in extent; while it has further been calculated that a certain oak-tree, within a period of six months, transpired, during the daytime eight and a half times more water than fell as rain on an area equal in circumference to the tree-top.¹ Just as the state of the fineness of the soil-particles has an important influence on the absorptive power of soils, so, too, it is found, it has an important bearing on the rate at which evaporation takes place. Evaporation goes on to the greatest extent in soils whose particles are compacted together, capillary action in this case taking place more freely, and effecting evaporation from a greater depth of soil. The stirring of the surface portion of the soil, as for example by hoeing or harrowing, has for this reason an important influence in lessening the amount of evaporation, and

¹ See Introduction, p. 55.

minimising the risks of drought, by breaking the capillary attraction. The amount of evaporation which takes place from a soil covered with a crop, depends largely on the nature of the crop; a deep-rooted crop, since it draws its moisture from a wider area of soil, being more effective in drying a soil than a shallow-rooted crop. The difference in the amounts evaporated from a cropped and a bare fallow soil has been shown at Rothamsted to equal a rainfall of nine inches, the crop being barley. The increase, of course, is due to the water which the crop transpires.¹

It may be generally said that the greater the absorptive power of a soil, the greater is its retentive power; for soils that most largely absorb water are the most reluctant to part with it.

While these properties are undoubtedly necessary for fertile soils, it is needless to add that they may be possessed by a soil to too great an extent. The soil that is unable to throw off any excess of water becomes cold and damp, and does not admit of proper tillage. Its pores become entirely choked up, and the circulation of air, which, as we shall see, is of so much importance, is rendered impossible. Plants in such a soil are apt to sicken and die, the water becomes stagnant, and certain chemical actions are caused which give rise to poisonous gases, such as sulphuretted hydrogen, &c. A stiff clayey soil offers a good example of the disadvantage of over-retentive-

¹ See Introductory Chapter, p. 55.

ness. Owing to the difficulty such soils experience in throwing off their excessive water, they are extremely difficult to till; and sowing operations are on that account apt to be delayed.

Power Plants have of absorbing Water from a Soil.

It is a strange fact, and one worth noticing in this connection, that the power plant-roots have of drawing their moisture from a soil, seems to depend on the retentive power of the soil. By this is meant that plants have not the means of exhausting the water in a retentive soil to such an extent as in a non-retentive soil.

In some extremely interesting experiments, carried out by the well-known German botanist Sachs, it was found that plants wilted in a loamy soil, whose water-holding capacity was 52 per cent, when its moisture reached 8 per cent; while in a sandy soil—water-holding capacity 21 per cent—the same species of plant did not wilt until its moisture reached $1\frac{1}{2}$ per cent. Here, then, we see that on one kind of soil the plant was able to live, and obtain sufficient water for its needs, while it died of thirst in another soil, although that soil contained quite as much moisture.

Speaking generally, we may say that Hellriegel's experiments have shown that any soil can supply plants with all the water they need so long as its

moisture is not reduced below one-third of the whole amount it can hold.¹

How to increase Absorptive Power of Soils.

The absence or presence, in excess, of the above properties, suggests a word or two on how these natural defects may, to a certain extent, be remedied artificially. It stands to reason, that if organic matter in a soil renders its absorptive power greater, a simple method of improving a soil defective in this property is by the addition of organic matter. One of the benefits of ploughing-in green crops on sandy soils is undoubtedly due to this fact; the addition of farmyard manure having also a similar effect. The absence of a sufficient amount of retentiveness, such as is found in sandy soils, in the same way suggests, as a remedy, the addition of clay; and, *vice versâ*, where the soil is too clayey, the natural method of improvement will be the addition of sand.²

Shrinkage of Soils.

In drying, soils shrink. Those which shrink least are sandy and chalky soils. Humus soils, on the other hand, shrink most.

¹ It is not exactly known why excess of water should prevent normal growth in the plant. Probably it is on account of the fact that free access of oxygen is hindered in such a case. The roots are thus not freely enough exposed to this necessary gas, and fermentative processes of the nature of nitrification are not promoted. It may be also due to the fact that the solution of plant-food is too dilute when such excess of water prevails.

² See Appendix, Note II., p. 98.

Most favourable Amount of Water in a Soil.

The amount of water in a soil most favourable for plant-growth is a question of considerable difficulty. Too great an amount of moisture renders the land cold; air cannot obtain access to the soil-particles, and the plants sicken and die. Hellriegel has found that as much as 80 per cent of what the soil can hold is hurtful to plants, and that from 50 to 60 per cent is the best amount.¹

Hygroscopic Power.

A property possessed by soils in relation to water, which is quite distinct from absorptive power, is their hygroscopic power. By this is meant their power of absorbing water from the air where it is present in the gaseous form. This property is identical with the property which will be adverted to immediately—viz., capacity for absorbing gases. The extent to

¹ Some experiments by E. Wollny show this. He found, when experimenting with *summer rape*, that the best results were obtained when the soil contained only 40 per cent of its total water-holding power; when the amount was either lessened or increased the results obtained fell off. The effect of either too little or too much water is seen in the development of the different organs of the plant as well as on its period of growth, much water seeming to retard the growth. The quality of the plant seems also to be influenced by this condition. Experiments on cereal grains by Wollny show that not merely is the texture of the grain influenced, but that much moisture lessens the percentage of nitrogen. Wollny is of the opinion that for crops generally, the best amount is from 40 to 75 per cent of the total water-holding capacity of the soil.

which soils possess this hygroscopic property seems to be regulated very much by the same conditions as regulate their ordinary absorptive power.¹ This property is considered to be of great importance in the case of soils in hot climates, where their agricultural value may be said to depend to a large extent upon it. The amount of water, however, absorbed in this way is, comparatively speaking, insignificant. Lastly, it may be observed that there are certain methods of drying soils afflicted with too much moisture. These consist in making open ditches, and thus relieving them of their superabundance of water, or in planting certain kinds of trees, such as willows and poplars. The amount of green surface presented by the large number of leaves of trees, from which the constant evaporation of water goes on, is very great. The consequence is that trees may be regarded as pumping-engines. It is from this cause that foresters have noticed that clay lands are apt to become wetter after the trees growing upon them have been cut down.²

Capacity for Heat in Soils.

A property which depends largely on those we have just been considering is the capacity soils possess of absorbing and retaining heat.³ The temperature of

¹ See Appendix, Note III., p. 99.

² See p. 55.

³ The effect of the temperature of the soil on the development of the plant is most important. This is especially marked at the period of germination, but is felt at subsequent periods of growth. Up to a

a soil, of course, largely depends on the temperature of the air; but this, we must not forget, depends also on the soil itself. The heat given forth by the sun's rays strikes the soil, with the result that, while so much of its heat is absorbed, a certain portion—and this will vary according to the nature of the soil—of its heat is radiated into the air.

The changes in the temperature of the soil naturally take place more slowly than the changes in the temperature of the air; the depth of soil thus affected by those changes varies also in different climes. It has been calculated that in temperate climes the changes of temperature occurring from day to night are not felt much below three feet down.

The Explanation of Dew.

We have, it may be stated, generally two processes going on. During the day the soil is engaged in absorbing its heat from the sun's rays; when night comes, and the sun goes below the horizon, the air is chilled below the temperature of the soil, which radiates out its stored-up heat into the air. The result is that the temperature of the soil is soon reduced below the temperature of the air, and the moisture, present in the air in the form of vapour, coming in contact with the cold surface of the earth, certain temperature the warmer the soil the more rapid the plant's development. In this country the temperature most favourable to growth is rarely exceeded, or indeed reached.

is condensed into dew, which is deposited, and is seen best early in the morning before the sun has had time to evaporate it again. Dew is most abundant in summer-time, for the reason that the difference in temperature of the day and night is then greatest. In winter-time it is seen as hoar-frost.

Heat of Soils.

The temperature of a soil, however, is due to other sources than the sun's rays. Whenever vegetable matter decays, there is always a certain amount of heat generated. Soils, therefore, in which there is a large amount of decaying vegetable matter, are certain to receive more heat from this source than soils of more purely mineral nature.

Heat in Farmyard Manure.

A good example of the amount of heat that accompanies fermentation, or decay of vegetable matter, is seen in the case of rotting farmyard manure. The danger of loss of the volatile ammonia from this cause is often great, and care must be taken to prevent fermentation going on too quickly, and the temperature from becoming too high.¹ The actual increase in the temperature of a soil effected by the addition of certain bulky organic manures, such as

¹ See Chapter on Farmyard Manure.

farmyard manure, may thus be considerable. In some experiments carried out at Tokio, Japan, it was found that the application of 20 tons of farmyard manure per acre increased the temperature of the soil to a depth of five inches, for a period of nearly a month, on an average, one and a half degrees Fahrenheit. The amount of water present in a soil, it may be noticed in passing, will have a considerable effect in regulating its temperature, a damp soil being, as a rule, a cold soil.

The Cause of the Heat of Fermentation.

It may be asked, How is the decay, or fermentation, of vegetable matter, such as farmyard manure, caused? or rather, To what is it due? Decay of any substance is just its slow combustion or burning. When a substance unites with the active chemical element in air—the oxygen gas—it is said to be oxidised. Now, this union of a substance with oxygen is the explanation of burning, and the phenomena of burning and decay are explained by the same chemical operation. When bodies decay, or when they burn, they unite with oxygen: when this union of a body and oxygen takes place very quickly, and the result is a flame and very great heat, then we call it burning; when, however, it takes place slowly, it is not called burning, but simply oxidation or decay. The ultimate products are the same, however, whether the body burns or decays; and the

process of decay is always accompanied by heat, as well as the process of burning.¹ It is not, of course, only the vegetable or organic matter in a soil that decays, but also the mineral matter. The oxidation, however, of the mineral matter in the soil takes place so slowly, and the amount of heat generated by this oxidation is so slight, that the temperature of the soil can scarcely be said to be much affected by it.

Influence of Colour of a Soil.

There is still another quality of a soil on which its temperature depends, and that is its colour. This may seem at first sight to be scarcely worth taking into account, and yet it has been shown to have a very striking influence on the temperature of a soil. This naturally is best seen in climates where there is a good deal of sun. Dark-coloured soils have a greater heat-absorbing capacity than light-coloured soils; and experiments carried out for the purpose of determining the extent of this influence have shown that under certain conditions the difference between a soil covered with a black substance, and one covered with a white substance, amounted to from 13° to 14° Fahr. Other things being equal, a crop on a dark-coloured soil will be sooner ripened than one on a light-coloured soil. A soil covered by a crop is cooler than one without any crop.

¹ As will be seen further on, the fermentation of organic substances is caused by the action of micro-organic life.

The Power Soils have for absorbing Gases.

We have just seen that one cause of the heat of soils is the oxidation which is constantly going on in all soils, but more rapidly in soils containing a large quantity of vegetable matter. This suggests a word or two on the power soils have of absorbing gases.

The chief gases in the atmosphere are oxygen and nitrogen. Both these gases are absorbed by soils, although not in similar proportions.¹ With regard to the former, it is well known that a plentiful supply of oxygen in the pores of the soil is a necessary condition of fertility. This was long ago experimentally proved by de Saussure, who showed that plants absorbed oxygen through their roots. At certain periods of their growth this demand for oxygen on the part of the plant is greater than at other times. For example, seeds in the process of germination require to have free access to a plentiful supply of oxygen. This fact emphasises the enormous importance of providing a good seed-bed, and of seeing that the seed is not buried too deeply.

Carbonic Acid and Ammonia.

In addition to oxygen and nitrogen, the air contains other gases which are absorbed by the soil. Of these, carbonic acid is the most abundant. By far the largest portion of the carbonic acid which the

¹ See Appendix, Note IV., p. 100.

soil obtains from the air, is washed down in solution in the rain.¹ Of the other constituents of the atmosphere, the combined forms of nitrogen—viz., *ammonia*, *nitric*, and *nitrous acids*—are the most important. These are all absorbed by the soil, but, like carbonic acid, they are chiefly washed down by the rain. The amount of ammonia which may be absorbed by a soil from the air, is very much greater than was formerly supposed. Some recent experiments by Schloesing, referred to in a following chapter,² show this. A damp soil may in the course of a year absorb far more ammonia than that washed down in rain.

Gas-absorbing Power of Soils varies.

The power of different soils to absorb these gases varies. This variation depends not only on their physical properties, but also on their chemical as well. Soils containing much organic matter have a greater capacity for absorbing gases than the more purely mineral ones.

Absorption of Nitrogen.

The absorption of nitrogen by the soil is a question of considerable importance. It will be referred to later on under the heading of the biological prop-

¹ Of course it must be remembered that a large amount of carbonic acid in soils comes from the decay of vegetable matter. Soils are twenty to one hundred times richer in carbonic acid than the air.

² See Chapter III., p. 119.

erties of soils, as it is fixed by the agency of micro-organisms.¹

To recapitulate, the chief physical or mechanical properties of a soil are its absorptive and retentive powers for water ; its capacity for heat ; and its power of absorbing gases. It will be easily seen how tillage operations are calculated to influence these physical properties of a soil. Thus, in the case of a stiff soil, tillage increases its power for absorbing the atmospheric gases, chiefly oxygen, which are so necessary for rendering its fertilising matters available. On the other hand, in a light and too open soil it may exert quite a contrary effect.

It may be also well to refer here to the important influence these physical properties exercise on the growth of the plant.

Plant-roots require a certain Openness in the Soil.

One of the functions of the soil is to support the plant in an upright position, and this is a function which requires in the soil a certain amount of compactness or firmness. On the other hand, however, a soil must not possess too great compactness, otherwise the plant-roots will experience a difficulty in pushing their way downwards. This is especially the case during the earlier periods of growth, when the plant-roots are as yet extremely tender, and experience great difficulty in overcoming much resistance. The import-

¹ See Introduction, p. 40.

ance of preparing a mellow seed-bed will be thus at once seen to be based on sound scientific principles; and this for a double reason. Not only does the young plant require every facility for developing its roots, but also, as has just been pointed out, an abundant supply of oxygen is of paramount importance during the process of germination.

Soil and Plant-roots.

The whole question of the influence of the mechanical condition of the soil on the development of plant-roots is one of the highest importance and interest, and is not so generally recognised as it ought to be.

Natural tendency of Plant-roots to grow downwards.

It may be taken as certain that the tangled condition of plant-roots is due to the resistance offered by the soil-particles, and that the natural tendency of the plant-root is to grow downwards. The roots, in short, would probably grow in as symmetrical a form as do the stalks or branches, were it not that they are hindered from so doing by the soil-particles. Where, then, the soil is such as to offer much hindrance, the growth of the plant cannot but be retarded. Some extremely interesting experiments have been performed by the eminent German chemist Hellriegel on the influence which the closeness of the soil-particles has on root-development. In these experiments peas

and beans were grown in moistened sawdust, more or less compactly compressed. It was found that when the sawdust was compressed to any extent, plant-growth took place very slowly, or entirely ceased.

The importance of having plant-roots as widely developed in the soil as possible, will be at once seen when we reflect that this means that the area of soil from which the plant derives its soil-food is thereby greatly increased. Another important consideration is, that the deeper plant-roots can penetrate in a soil, the more able—other conditions being equal—is the plant to withstand the action of drought, as it can draw water for its needs from the deeper layers of the soil, long after a plant, whose roots do not penetrate so deeply, has wilted.

Plants require Room.

Another important bearing tillage has on plant-growth may here be discussed. A problem of considerable difficulty is presented in the question, How many individual plants will a certain piece of soil support in a healthy way? For as plants require room, it is imperative that they be not too closely crowded together.

The question resolves itself pretty much into one of quality against quantity.

Experiments on this subject have shown that a certain area of soil is only able to support the healthy growth of a certain number of plants. If the limit be exceeded, the result is imperfect development.

Number of Plants on certain Area increased by Tillage.

It is obvious, however, that the more thoroughly tilled a soil is, the greater will be the number of plants it will be possible to grow on it. The roots, instead of being forced to spread themselves along the surface-soil, and thus take up a large amount of room, will find no difficulty in striking downwards. Two or three plants may thus be enabled to grow in a thoroughly tilled soil in the same space as only one could before tillage.

American and English Farming.

The above considerations throw considerable light on what seems to many farmers a strange anomaly—viz., the fact that the return of farm produce per acre on American farms is, as a rule, very much less than that from our own impoverished soils in this country. To many, at first sight, this seems to be in direct contradiction to our common belief, and to point to the conclusion that the virgin soils of America are, after all, actually inferior in fertility to the soils of Britain.

It is not, however, necessary to draw this conclusion, as the facts of the case admit of another explanation. The inferior returns obtained from American farms are due, not to the fact that the American soil is less fertile than the British—for this is not true—but to the fact that it is less *intensively* cultivated.

In America land is cheap and labour is dear; it is consequently found to be more economical to cultivate a large tract of land less thoroughly than a small area more thoroughly. In Britain the reverse is the case, labour being cheap and land being dear. It is thus necessary to make the land go as far as possible, and produce as heavy a crop as it is possible to produce. There can be little doubt, that were American farming to be carried on as intensively as is British farming, the present yield would be at least probably doubled.

We have now to consider the second class of properties which influence the fertility of a soil. These are *chemical*.

II. Chemical Composition of a Soil.—Chemically considered, the soil is a body of great complexity. It is made up of a great variety of substances. The relations existing between these substances and the plant are not all of equal importance; some—and these form by far the largest proportion of the soil-substance—are concerned in acting simply as a mechanical support for the plant, and in helping to maintain those physical properties in the soil which, as we have just seen, exercise such important functions in the plant's development.

Fertilising Ingredients.

A small portion of the soil-substance, however, takes a very much more active part in promoting

plant-growth, by acting as direct food of the plant. As we have already seen in the Introductory Chapter,¹ the substances which have been found in the ash of plants are the following: *potash, lime, magnesia, oxide of iron, phosphoric acid, sulphuric acid*, soda, silica, chlorine, oxide of manganese, lithia, rubidia, alumina, oxide of copper, bromine, and iodine. The general presence of some of these substances is doubtful; the presence of others, again, probably purely accidental; while some are only found in plants of a special nature, as, for instance, iodine and bromine, which are only found in the ash of marine plants.

Of these ash constituents, only the first six substances—those marked in italics—are absolutely necessary to plant-growth. In addition to these six ash constituents, the plant also derives its *nitrogen*, which is a necessary plant-food, chiefly from the soil.²

Importance of Nitrogen, Phosphoric Acid, and Potash.

But of these seven constituents of the soil which are necessary to plant-growth, some have come to be regarded by the agriculturist with very much greater interest than others. This is due to the fact that they are normally present in the soil in very much smaller quantities than is the case with the other equally necessary food ingredients; that, in short, they are nearly invariably present in the soil, in a readily available form, in lesser quantities than the plant is able to

¹ See Introductory Chapter, p. 54.

² See pp. 44 and 135.

avail itself of, and often, as in impoverished or barren soils, in quantities too small for even normal growth. These ingredients are *nitrogen*, *phosphoric acid*, and *potash*.¹

The importance of seeing that all the necessary plant ingredients are present in a soil in proper quantities will be at once properly estimated when it is stated that the absence or insufficiency in amount of one single ingredient is capable of preventing the growth of the plant, although the other necessary ingredients may be even abundantly present.

With lime, magnesia, iron, and sulphuric acid, most soils are abundantly supplied. The substances with which the farmer has to concern himself, then, are nitrogen, phosphates, and potash. It is these substances therefore, that, as a rule, are alone added as manures.

Chemical Condition of Fertilising Ingredients in Soil.

But in considering the chemical properties of a soil, a simple consideration of the quantity of the different ingredients present is not enough. A very important consideration is their chemical condition. Ere any plant-food can be assimilated by the plant's roots, it must first be rendered soluble. The quantity of soluble, or, as it is known, *available*, plant-food in a soil is very small. It is, of course, being steadily added to each day by the process of disintegration constantly going on in soils.

¹ Occasionally also *lime*.

Amount of Soluble Fertilising Ingredients.

The exact nature and dissolving capacity of the soil-water, charged as it is, to a greater or less extent, with different acids and salts, as well as the dissolving power of the sap of the rootlets of the plant itself, render the exact estimation of the available fertilising constituents wellnigh impossible. An approximate estimate, however, may be obtained by treating the soil with pure water and dilute acid solutions. The treatment of the soil with dilute acid solutions is for the purpose of simulating, as nearly as may be done, the conditions it is submitted to in the soil. By treating a soil with water, we obtain a certain amount of plant-food dissolved in the water. This can only be regarded as indicating approximately the amount available at that moment to the plant. But every day, thanks to the numberless complicated reactions going on in the soil, this soluble plant-food is constantly being added to. Considerations such as the above, together with our ignorance as to the exact combinations in which the necessary minerals enter the plant, will serve to indicate the great difficulty of this part of the subject.¹

Value of Chemical Analysis of Soils.

It is largely for these reasons that a chemical analysis of a soil is from one point of view of little

¹ See Appendix, Notes V. and VI., pp. 100, 101.

value in giving evidence of its actual fertility. What it demonstrates more satisfactorily is its potential fertility. It is useful in revealing what there is present in it, not necessarily, however, in an available condition. Under certain circumstances it may be made of great value, as, for example, when we are anxious to know what will be the result of certain kinds of treatment, such as the application of lime, &c.

It is hardly advisable, therefore, to place before the reader a number of soil analyses. That he may obtain an approximate idea of the composition of a soil, one or two representative analyses will be found in the Appendix,¹ along with a short account of the chief minerals out of which soils are formed.

A point of considerable interest is the quantity per acre different soils contain of nitrogen, phosphoric acid, and potash. Although the amount of these ingredients when stated in percentage seems very trifling, yet when calculated in lb. per acre, it is seen to be in large excess of the amount removed by the different crops. This question will be dealt with in succeeding chapters.

A point of further interest is the chemical form in which the necessary plant constituents are present in the soil. For information on this point the reader is referred to the Appendix.²

The third class of properties which affect the fer-

¹ Note VI., p. 101.

² Note VII., p. 107.

tility of a soil are those which have been termed the *biological*.

III. Biological Properties of a Soil.—The important functions which modern discoveries have shown to be discharged by minute organic life in the terrestrial economy are nowhere more strikingly exemplified than in the important *rôle* they perform in the soil.

Bacteria of the Soil.

The soil of every cultivated field is teeming with bacteria whose function is to aid in supplying plants with their necessary food. The nature of, and the functions performed by, these organisms differ very widely. Regarding many of them we know very little; every day, however, our knowledge is being extended by the laborious researches of investigators in all parts of the world, and it is to be anticipated that ere long we shall be in possession of many facts regarding the nature and the method of the development of these most interesting agents in terrestrial economy. That they are present, however, in enormous numbers in all soils we have every reason to believe, one class of organism connected with the oxidation of carbonic acid gas being estimated to be present to the extent of over half a million in one gramme of soil¹ (Wollny and Adametz). One class—and their

¹ Even larger estimates of the number of germs in a gramme of soil

importance is very great in agriculture—prepare the food of plants by decomposing the organic matter in the soil into such simple substances as are easily assimilated by the plant. The so-called “ripening” of various organic fertilisers is effected, we now know, entirely through the agency of bacteria of this class. Plant-life is unable to live upon the complex nitrogenous compounds of the organic matter of the soil, and were it not for bacteria these substances would remain unavailable. Attention will be drawn in the Chapter on Farmyard Manure to this question more in detail. Of these bacteria, among the most important are those which are the active agents in the process known as “nitrification”—*i.e.*, the process whereby organic nitrogen and ammonia salts are converted into nitrites and nitrates. The presence of these organisms, it would appear, is indispensable to the fertility of any soil. There are organisms, on the other hand, which have the power of reversing the work of the nitrification bacteria by converting nitrates into other forms of nitrogen. The reduction of nitrates in the soil is often the source of much loss of valuable nitrogen, which escapes in the free state, so that the action of bacteria is not altogether of a beneficial nature.

have been made—from three-quarters to one million (Koch, Fülles, and others).

Three Classes of Organisms in the Soil.

So far as the subject has been at present studied, the micro-organisms in the soil may be divided into three classes.¹

First Class of Organisms.

We have, first of all, those whose function it is to oxidise the soil ingredients. Organisms of this class may act in different ways. They may assimilate the organic matter of the soil and convert it into carbonic acid gas and water; or, on the other hand, they may oxidise it by giving off oxygen. Some of these organisms, whose action is of the first kind, choose most remarkable materials for assimilation. One has been found to require ferrous carbonate for its development, which it oxidises into the oxide (Winogradsky); while another,² the so-called sulphur organism, converts sulphur into sulphuretted hydrogen according to some, and according to others into sulphates. To this class of organism the nitrifying organisms belong. As will be seen more fully in a subsequent chapter, two distinct organisms connected with this process have already been isolated and studied—one of these effecting the formation of nitrites from or-

¹ These organisms consist of molds, yeast, and bacteria, the last-named being most abundant. In the surface-soil, among the bacteria, bacilli are most abundant. Micrococci are not abundant.

² Investigated by Winogradsky, Olivier, De Rey Pailhade, and others.

ganic nitrogen or ammonia salts, and the other the conversion of nitrites into nitrates. The second method in which these oxidising organisms act is by giving off oxygen. There is much interest attaching to this fact, as it was supposed till quite recently that all evolution of oxygen in vegetable physiology was dependent on the presence of light, and also intimately connected with chlorophyll, or the green colouring matter of plants. It would seem, however, that among the soil organisms these conditions are not necessary, and the evolution of oxygen may be carried on in the case of colourless organisms as well as in the case of light. With organisms of this kind every soil is probably teeming. A typical example is the organism which is the active agent in the oxidation of carbonic acid gas, and which has already been referred to as existing in the soil in such numbers.¹

The Second Class of Organisms in the Soil.

The second class of organisms are those which reduce or destroy the soil constituents. The most important of these, from the agricultural point of view, are those which effect the liberation of nitrogen from its compounds. In the putrefaction of organic matter the organisms chiefly act, it is probable, in the

¹ Organisms of this kind have been investigated among others by Heraus, Hueppe, and E. Wollny. According to the two first-mentioned investigators, certain colourless bacteria effect the formation in the absence of light from humus and carbonates a body resembling in its nature cellulose.

entire absence of atmospheric oxygen; but it would seem, however, that they may also act in the presence of oxygen. It is through their agency that the soil may lose some of its nitrogen in the "free" form. To this class belong the denitrifying organisms already referred to which reduce the nitrates and nitrites in the soil.¹

Third Class of Organisms.

The third class of organisms are those by whose agency the soil is enriched. Of this class those fixing the free nitrogen from the air are the most important. The nature of these organisms is still somewhat obscure, but that leguminous plants have the power of drawing upon this source of nitrogen is now a firmly established fact. Further reference to these interesting organisms may be delayed to another chapter.

The important point to be emphasised is, that for the healthy development of these organisms, which are so necessary in every fertile soil, certain conditions must exist. These necessary conditions will be treated more in detail later on. It is sufficient to notice that they have to do with the physical properties as well as the chemical composition of the soil. This furnishes a further reason for the necessity of having the mechanical condition of a soil satisfactory

¹ Investigated by Springer, Gayon and Dupetit, Dehérain, and Marguenne.

Recapitulation.

From what we have said, it will be seen that the question of soil-fertility is a very complicated one, and depends on numerous and varied conditions; that the properties which constitute fertility, while seemingly very widely different in their nature, in reality influence one another to a very great extent; that not merely is the presence in a soil of the necessary plant constituents necessary to fertility, but that the possession by the soil of certain physical or mechanical properties is equally necessary; while, lastly, we have seen that the presence of certain micro-organic life is bound up with the problem of fertility in a very direct and practical manner.

The importance of the conditions, other than those of a purely chemical nature, have been thus far somewhat prominently emphasised, for the reason that in what follows attention will be almost exclusively devoted to the purely chemical conditions of fertility. It is well, then, to realise that, while the latter conditions are by far the most important, so far as the farmer is practically concerned, inasmuch as they are most under his control, they are not the only conditions, and are not by themselves able to control fertility.

APPENDIX TO CHAPTER I.

NOTE I. (p. 68).

THE following determinations by Schübler show the absorptive power of different kinds of soil-substances. These were obtained by soaking weighed quantities of the soil in water, and allowing the excess of liquid to drain away, and weighing the wet earth.

	Per cent of water absorbed by 100 parts of earth.
Siliceous sand	25
Gypsum	27
Calcareous sand	29
Sandy clay	40
Strong clay	50
Arable soil	52
Fine calcareous earth	85
Garden-earth	89
Humus	190

It has been calculated that the absorptive power of a mixture of different substances is not simply equal to the sum of their separate ingredients.

NOTE II. (p. 74).

EVAPORATION.

The retentive property of a soil for water tends to retard evaporation. The following table by Schübler shows the rate at which evaporation proceeds in different soils. The

experiment was conducted in the following way. The soil experimented upon was saturated with water and spread over a disc, and allowed to evaporate for four hours, when it was weighed. The amount of time required for the evaporation of 90 per cent of the water was also estimated. Of 100 parts of water in the wet soil there evaporated, at 60° Fahr.—

From—	In four hours— per cent.	Time required to evaporate 90 per cent.	
		Hours.	Minutes.
Quartz	88	4	4
Limestone	76	4	44
Sandy clay	52	5	1
Stiffish clay	46	6	55
Loamy clay	46	7	52
Pure grey clay	32	11	17
Loam	32	11	15
Fine calcium carbonate	28	12	51
Humus	21	17	33
Magnesium carbonate	11	33	20

NOTE III. (p. 76).

HYGROSCOPIC POWER OF SOILS.

Davy found the hygroscopic power of soils to be as follows. He found that 100 parts by weight of three samples of different sands absorbed 3, 8, and 11 parts of water, respectively, in one hour; while three loams absorbed similarly 1.3, 1.6, and 1.8 parts.

The following samples of soil were dried at 212° Fahr., and exposed to an atmosphere saturated with water and a temperature of 62° Fahr., when it was found they absorbed the following amounts in twelve hours' time:—

Quartz sand	0.0
Limestone sand	0.3
Lean clay	2.1
Fat clay	2.5
Clay soil	3.0
Pure clay	3.7
Garden-loam	3.5
Humus	8.0

NOTE IV. (p. 81).

GASES PRESENT IN SOILS.

The air which we find enclosed in the pores of the soil is distinctly *poorer* in oxygen than ordinary air. Bous-singault found the percentage of oxygen in a sandy soil, freshly manured and wet with rain, to be as low as 10.35 per cent; while the air in forest-soil contained 19.5 per cent of oxygen, and .93 per cent of carbonic acid. The percentage of oxygen in soils depends on the rate of decay of the organic portions. The depth of the soil-layer also determines the quantity. This is owing to the fact that diffusion takes place more slowly deep down than near the surface.

NOTE V. (p. 90).

AMOUNT OF SOLUBLE PLANT-FOOD IN THE SOIL.

Two of the most reliable methods of ascertaining an approximation of the quantity of soluble soil constituents are (1) by treating the soil with distilled water, and (2) by analysing the drainage-water. With regard to the former of these two methods, it has been found that even the amount of fertilising matter dissolved out by pure distilled water varies. This variation depends on the amount of distilled water used, as well as the length of time the soil is left in contact with the solvent. By washing the soil with different quantities of water, different amounts of soluble soil ingredients will be found to have been washed out; for although the first washings contain by far the greater portion of the soluble matter, each subsequent washing will be found to contain further quantities.

A number of experiments have shown that 1000 parts of distilled water dissolved out from different soils from one half to one and a half parts of soluble constituents; or

from .05 to .15 per cent. Of this soluble matter from 30 to 67 per cent is mineral in its nature, and from 33 to 70 per cent organic. Poor sandy soils yield the minimum quantity, while peaty soils yield the maximum. The quantity of soluble matter in a regular peaty soil may vary from .4 to 1.4 per cent; this consists chiefly, however, of organic matter. (See Johnson's 'How Crops Feed,' p. 312.)

Perhaps a more satisfactory method is by analysing the drainage-water of a soil. This has been found to vary very considerably in composition. The average of a large number of analyses are .04 to .05 per cent of dissolved matter. Of this dissolved matter the largest proportion is made up of organic matter, nitric acid, lime, and soda salts. It must be borne in mind, however, that even the drainage-water does not furnish an exact indication of the amount of dissolved matter in a soil. Much, perhaps the largest proportion of dissolved matter, never finds its way into the drainage-water. That contained by the drainage-water really represents the surplus quantity of dissolved matter which the soil is unable to retain, and which is thus washed by the rain into the drains. The composition of drainage-water is interesting, as it shows that, practically speaking, all the necessary plant ingredients are in a state of solution in the soil.

NOTE VI. (p. 90).

CHEMICAL COMPOSITION OF THE SOIL.

The most important substances present in soils are as follows: silica, alumina, lime, magnesia, potash, soda, ferric oxide, manganese oxide, sulphuric acid, phosphoric acid, and chlorine. Of these substances the presence of alumina, silica, lime, and, in certain cases, magnesia, along with the organic portion of the soil—the humus—has the chief influence in determining the nature and the physical properties of a soil.

In order to clearly understand to what it is soils owe the nature of their chemical composition, it is necessary to consider the composition of some of the chief minerals out of the disintegration of which soils are formed.

While we know of some seventy elements present in the earth's crust, it is practically made up of only some sixteen. These sixteen are—oxygen, silicon, carbon, sulphur, hydrogen, chlorine, phosphorus, iron, aluminium, calcium, magnesium, sodium, potassium, fluorine, manganese, and barium.¹ Of these, oxygen is by far the largest constituent, forming, roughly speaking, about 50 per cent.

The main mass of the rocks consists of silica, and this is generally combined with alumina, as in clay, forming aluminium silicate, and with the commoner alkalies and alkaline earths. Another extremely abundant compound is carbonate of lime, which, as limestone, chalk, and marl, forms one-sixth of the earth's total rocks.

The word “mineral” means a definite chemical compound of natural occurrence. The number of minerals is very great, and it is impossible to go into the subject here. Reference can only be made to a few of the more prominent ones, which are chiefly concerned in the formation of soils.

Those formed out of silicates are, from the agricultural point of view, the most important, as they form a very large group; and it is by their disintegration that soils are chiefly formed. They consist of silica and alumina, along with various other substances, chiefly alkalies and alkaline earths. It is important to note one peculiarity about the solubility of silicates. We have two classes of silicates: the one, which is called “acid,” and contains an excess of

¹ Composition of the earth's solid crust in 100 parts by weight:—

Oxygen	. . . 44.0 to 48.7	Calcium	. . . 6.6 to 0.9
Silicon	. . . 22.8 „ 36.2	Magnesium	. . . 2.7 „ 0.1
Aluminium	. . . 9.9 „ 6.1	Sodium	. . . 2.4 „ 2.5
Iron	. . . 9.9 „ 2.4	Potassium	. . . 1.7 „ 3.1

(Roscoe's 'Lessons in Elementary Chemistry,' p. 8.)

silica; the other, "basic," and which contains an excess of base. Now, while the former of these is more or less insoluble, the second is soluble. This fact has an important signification in the process of the disintegration of the silicate minerals we are about to consider.

The first and most important class are the *Felspars*. Felspar is not really a definite mineral, with a definite chemical composition, but rather the name of a class of minerals of which there are several different kinds. The felspars are composed of silica and alumina, along with potash, soda, and lime, with traces of iron and magnesia. Their principal constituents, however, are silica and alumina, along with either potash, soda, or lime. According as the base potash, soda, or lime predominates, the felspar is known as Orthoclase, Albite, and Oligoclase, respectively.

The following are the analyses of the three minerals (by the late Dr Anderson):—

	Orthoclase.		Albite.		Oligoclase.	
	1.	2.	1.	2.	1.	2.
Silica . . .	65.72	65.00	67.99	68.23	62.70	63.51
Alumina . . .	18.57	18.64	19.61	18.30	23.80	23.09
Peroxide of iron	traces	0.83	0.70	1.01	0.62	none
Oxide of man- ganese }	traces	0.13	none	none	none	none
Lime . . .	0.34	1.23	0.66	1.26	4.60	2.44
Magnesia . . .	0.10	1.03	none	0.51	0.02	0.77
Potash . . .	14.02	9.12	none	2.53	1.05	2.19
Soda . . .	1.25	3.49	11.12	7.99	8.00	9.37
	100.00	99.47	100.08	99.83	100.79	101.37

According as these various felspars are present in a soil, so will the quality of the soil be. It stands to reason that as the presence of potash in a soil is one of the distinguishing features of its fertility, much will depend on the

extent to which the orthoclase felspar is present ; and also, not only on the extent, but on the state and degree of its disintegration. It is important to note the method of this disintegration. It is effected by the absorption of water. This water is not merely absorbed mechanically, but actually enters into the composition of the mineral. It is not present as moisture merely, capable of being expelled at ordinary boiling temperature, but it forms what is known as water of composition. In this process of hydration, the mineral loses its lustre and crystalline appearance, crumbles away into a more or less—according to its state of disintegration—powdery mass. A very great change is also effected in its chemical composition ; it loses nearly all its base. This is effected in the following way. As water enters into the mineral's composition, it sets free a certain portion of the base ; there is thus formed a basic silicate, which, being soluble in water, is washed away in solution. This change may be illustrated by quoting the analysis of a kaolin clay formed by the disintegration of orthoclase felspar.

Kaolin Clay formed by disintegration of Orthoclase.

Silica	46.80
Alumina	36.83
Peroxide of iron	3.11
Carbonate of lime	0.55
Potash	0.27
Water	12.44
	<hr/>
	100.00

The chief difference here is the almost total loss of potash and a portion of the silica, and the gain of water. The other constituents practically remain insoluble.

Another important mineral is *Mica*. Its composition is not unlike felspar. It contains silica, alumina, and iron, in considerable quantities, also magnesia and potash. There are two kinds of mica—that containing potash, and that containing magnesia, in excess. The analyses of

These two kinds are as follows (by the late Dr Anderson):—

	MICAS.	
	(a) Potash.	(b) Magnesia.
Silica	46.36	42.65
Alumina	36.80	12.96
Peroxide of iron	4.53	none
Protoxide of iron	none	7.11
Oxide of manganese	0.02	1.06
Magnesia	none	25.75
Potash	9.22	6.03
Hydrofluoric acid	0.70	0.62
Water	1.84	3.17
	<hr/>	<hr/>
	99.47	99.35
	<hr/>	<hr/>

The decomposition of mica is very slow, however, as it is a peculiarly hard mineral.

Other important minerals are *Hornblende* and *Augite*. These are composed of silica, alumina, iron oxide, manganese oxide, lime and magnesia. These are the chief minerals out of which soils are formed. It is scarcely necessary to say that few soils are made up out of any of these three minerals alone. Nearly all rocks are formed out of a mixture of these minerals. Where, however, any one mineral predominates over the rest, the nature of the soil will be thereby affected. In order to illustrate this, it may be well to mention the composition of one or two of the commoner rocks.

1. *Granite*, which is so abundant in certain parts of the north of Scotland, and which gives rise to the soils in the neighbourhood of Aberdeen, is made up of a mixture of quartz, felspar, and mica. It depends on the felspar present—*i.e.*, whether it is orthoclase, oligoclase, or albite—whether the soil will be rich in potash or not. Granite containing orthoclase felspar produces a fairly fertile soil. An important consideration, which is apt to complicate this question, is the situation of such soils. They are generally so high above sea-level, that their fertility is seriously impaired on these grounds.

2. *Gneiss*, another common rock, is similar in composition, only that it contains very little felspar, and a correspondingly greater amount of mica.

3. *Syenite* contains quartz, felspar, and hornblende.

The rocks of which greenstone and trap are types, are found very largely scattered over the country. They are of two kinds, diorite and dolorite.

4. *Limestone* is of two great classes. We have (1) Common, (2) Magnesian. The following are the analyses of these two classes by Dr Anderson:—

	COMMON.		MAGNESIAN.	
	Mid-Lothian	Sutherland.	Sutherland.	Dumfries.
Silica	2.00	7.43	6.00	2.31
Iron oxide and alumina }	0.45	0.76	1.57	2.00
Carbonate of lime	93.61	84.11	50.21	58.81
Carbonate of magnesia }	1.62	7.45	41.22	36.41
Phosphate of lime	0.56	...	...	...
Sulphate of lime	0.92	...	...	...
Organic matter	0.20	...	...	...
Water	0.50	...	...	...
	99.86	99.75	99.00	99.53

Clays are formed by the disintegration of any of the crystalline rocks; the purest clays being formed from felspar. A pure clay consists simply of silica and alumina, all the other constituents having been washed out. Disintegration, however, seldom reaches such an extent; otherwise clay soils would be completely barren, which they are notably not. The impurities present in clay, which consist of alkalis, especially potash and other mineral ingredients of the plant, are what confer on clay soils their fertility.

clays differ, however, very considerably in their composition. The following is an analysis of a clay soil by Dr Anderson :—

Silica	60.03
Alumina	14.91
Peroxide of iron	8.94
Lime	2.08
Magnesia	4.22
Potash	3.87
Soda	0.06
Water and carbonic acid	5.67
	<hr/>
	99.72

NOTE VII. (p. 91).

FORMS IN WHICH PLANT-FOODS ARE PRESENT IN SOIL.

The forms in which the bases necessary for plant-food are present in the soil, are chiefly as *hydrated silicates*, and in combination with organic acids, forming humates, &c., as well as in the form of sulphates and chlorides.

Phosphoric acid is present in combination with iron, alumina, or lime, or possibly also as magnesium-ammonium-phosphate. Sulphuric acid is generally present in a more or less insoluble condition, in combination with iron and lime; whereas chlorine is combined with the alkali bases in an easily soluble form. An important point is as to the form in which the plant absorbs these food constituents. In this connection reference may be made to a theory put forward by a very distinguished French agricultural chemist, Professor Grandeau. His theory is that the necessary ingredients of plant-food are absorbed into the plant as humates, or, at any rate, that the medium of this transference is humic acid, and organic acids of a similar nature. This theory, however, while ingenious, has not yet been supported by sufficient evidence to make its acceptance advisable. It is probable that it is only in

the form of soluble salts that the plant can absorb its food. It is quite probable, however, at the same time, that the exact form in which the different food substances enter the plant may be largely determined by circumstances. According to Nobbe, chloride of potassium is the most suitable form of potassium salts, although the plant may absorb its potassium as sulphate, phosphate, or even silicate.

CHAPTER II.

FUNCTIONS PERFORMED BY MANURES.

HAVING now considered the general conditions on which fertility of soil depends, we are in a position to deal with the nature and function of manures.

Manures may be classified in several different ways, and a considerable amount of confusion is sometimes caused by the variety of classification adopted by different writers on this subject.

Etymological meaning of the word Manure.

Let us, in the first place, clearly understand what we mean by a manure. The word manure comes from the French word *manœuvrer*, which simply means "to work with the hand," hence "to till," and this etymological meaning of the word illustrates the old belief in the function of manures. We have already seen in the historical introduction that, according to Tull, the true and only function of manures was to aid in the pulverisation of the soil by fermentation. In advancing

his system of *thorough tillage*, he claimed that since tillage effected the pulverisation of the soil, where it was practised, manures could be dispensed with.

Definition of Manures.

We no longer, of course, attach this old meaning to the word. The word manure is now applied to any substance which by its application contributes to the fertility of a soil. As has been shown in the previous chapter, the substances necessary for plant-growth which are apt to be lacking in a soil, are only generally three in number—viz., *nitrogen*, *phosphoric acid*, and *potash*. A manure, therefore, is understood to be any substance containing these ingredients, either singly or together, and its commercial value is determined by the amount it contains of these substances. But while this is so, it must not be forgotten that if we define a manure to be a substance which contributes in any way to the fertility of the soil, substances other than these above mentioned may be fairly regarded as manures. The fertility of a soil, we have seen, depends not merely on the presence of certain constituents, but also on their chemical condition—*i.e.*, whether they are easily soluble or not. It further depends, as we have also seen, on the possession by the soil of certain mechanical and biological properties. Thus there are substances which act upon the soil's inert fertilising matter, and by their action convert it into a more speedily available form. There are other

substances which by their application exert a considerable effect on the texture of the soil, and thereby influence its physical and biological properties. All such substances, according to the above definition of a manure, must be included under the term. It will thus be seen that since fertility in a soil can be promoted in a variety of ways, and the functions performed by manures are of different kinds, we can divide them into different classes, according to their respective action.

Different Classes of Manures.

In the first place, we can divide manures into two great classes,—(1) those supplying to the soil necessary plant-food constituents, and thus contributing directly to fertility; and (2) those influencing soil-fertility in an indirect manner. The first class we may call *direct* manures, and the second *indirect*. Those two classes admit further of being subdivided into other smaller classes. Among the direct manures we have a number of subdivisions in use. They may be divided into *general* manures and *special* manures, according as they contain all the elements necessary for plant-growth, or only some of them; or they may be divided according to their source into *natural* and *artificial*, *mineral* and *vegetable*. Similarly we have a number of subdivisions among the second class, depending on the special nature of the action they exert. Some manures act in both capacities—both directly

and indirectly—and in order that their value be fully appreciated must be studied under both heads. The most striking example of such a manure is farmyard manure. There are other manures which may in certain circumstances act in two different ways. Such a substance is lime. There are soils which are actually lacking in a sufficiency of lime for the needs of crops. On such soils an application of lime would act both as a direct and also as an indirect manure. There may also be cases of an exceptional nature, in which magnesia salts or even iron salts may act as direct manures. Many manures commonly regarded as purely direct manures would exert an indirect influence were the quantities in which they were applied sufficiently large. This is the case, indeed, with many artificial manures, such as guano, bones, nitrate of soda, and basic slag. It has been claimed for nitrate of soda that it not merely promotes fertility by supplying nitrogen in its most available form to the soil, but that the soda it contains exerts a valuable indirect influence in consolidating the soil and increasing its absorptive powers. When we reflect, however, on the small quantity of this manure which is applied per acre, its mechanical influence must be insignificant. The same applies to basic slag, which contains a considerable quantity of free lime in its composition. As this manure, however, is sometimes applied in considerable quantities, it is reasonable to suppose that its indirect value may not be altogether insig-

nificant. Indeed we have proof of this in the fact that its most favourable action has been found to be on soils rich in organic matter.¹ The action of bones and guano, and indeed of all other manures containing a large percentage of decomposable organic matter, is likewise of a double nature, inasmuch as their decomposition or putrefaction in the soil gives rise to the formation of carbonic and organic acids, which are capable of exerting a chemical action on the soil ingredients. There is one point in connection with the action of these manures which is worthy of notice, and it is that, however slight their indirect value may be, their action as a direct manure is very much accelerated by the way in which their organic matter putrefies. In short, they may be described as providing, to a certain extent, the solvents which render them available for the requirements of the plant. It may be here convenient to classify the manures which we intend subsequently to deal with.

I. Manures, action of which is both direct and indirect—*e.g.*, *green manures*, *farmyard manure*, *composts*, and *sewage*.

II. Manures which may be regarded as having only a direct action—*e.g.*, *guano* of all kinds, *bones* in all forms, *nitrate of soda*, *sulphate of ammonia*, *dried blood*, *superphosphates*, *mineral phosphates* of all kinds, *horns* and *hoofs*, *shoddy*, *wool-waste*, *fish-guano*, *muriate of potash*, *sulphate of potash*, and *kainit*.

¹ See Chapter on Basic Slag.

III. Manures which may be regarded as having only an indirect value—*e.g.*, *lime*, *mild* and *caustic*, *marl*, *gypsum*, *salt*, &c.

We shall now proceed to discuss the nature and action of these different manures, starting with those exercising both a *direct* and *indirect* influence. Before doing so it may be well to consider the occurrence and natural sources of the three important soil constituents, nitrogen, phosphoric acid, and potash, with a view of seeing to what extent these are being removed from our soils by the various natural processes constantly going on, as well as by the crops, and how far their natural sources are capable of making good this loss—in short, to clearly understand the economic reasons for the application of artificial manures.

CHAPTER III.

THE POSITION OF NITROGEN IN AGRICULTURE.

OF manurial ingredients, nitrogen is by far the most important, and on the presence and character of the nitrogen it contains, the fertility of a soil may be said to be most largely dependent. Most soils, as a rule, are better supplied with available ash ingredients than with available nitrogen compounds. The expensive nature of most artificial nitrogenous manures also, gives to nitrogen the first position from an economic point of view. A thorough study, therefore, of the different forms in which it exists in nature, of the numerous and complicated changes it undergoes in the soil, by which it is prepared for the plant's needs, of the relation of its different forms to plant-life, and of the natural sources of its loss and gain, is of the highest importance if we are to hope to understand the difficult question of soil-fertility.

The Rothamsted Experiments and the Nitrogen question.

The position of nitrogen in agriculture is a question

of great difficulty and complexity. It has engaged much attention, and has had devoted to its elucidation much elaborate and painstaking research. To the Rothamsted experiments we owe most of the information we possess on the subject, and the facts contained in this chapter are almost entirely derived from the results of these famous experiments, as embodied in the memoirs and writings of Messrs Lawes, Gilbert, and Warington.

Different forms in which Nitrogen exists in Nature.

We have already referred to the nitrogen question in the historical introduction. In order, however, to have a comprehensive view of the subject, it may be well to recapitulate some of the facts there mentioned.

Nitrogen, as we have already seen, exists in the "free" or elementary condition, as nitrates and nitrites, as ammonia, and in a large number of different organic forms.

Nitrogen in the Air.

It occurs in greatest abundance (amounting to about 80 per cent) in the first of these forms in the air. That this free nitrogen, which is practically unlimited in quantity,¹ has originally been the source of all its

¹ The total amount of nitrogen in the air has been estimated approximately at four million billion tons.

other forms, is of course obvious. But this conversion of free nitrogen into the various compound forms in which it occurs throughout the mineral, vegetable, and animal kingdoms, has been a process effected by a variety of indirect methods, and only at the expense of a vast amount of time. For practical purposes, the free nitrogen of the air may be regarded chiefly as a non-available source for most bodies containing it. It may be described as of all forms of nitrogen the least active, as far as plant-life is concerned.

Relation of "free" Nitrogen to the Plant.

The relation of the "free" nitrogen to the plant has formed the subject of much research, more especially during the last few years, and a brief epitome of the main results arrived at has already been given in the Introductory Chapter.¹

That this source of nitrogen is not so inaccessible to the plant as was formerly believed, has now been abundantly proved. As the considerations which have led to this conclusion, and have suggested the very recent elaborate experiments on the fixation of free nitrogen by the plant—the results of which bid fair, it would seem, to largely revolutionise our agricultural practice—have been due to the study of the relation of the soil-nitrogen to the plant, it will be best to defer further discussion of this question till we have dealt with the other sources of nitrogen.

¹ See Introductory Chapter, pp. 40 to 45.

Combined Nitrogen in the Air.

In addition to nitrogen in the free state, air contains very small quantities of this element in combined forms. We have it in minute traces as nitrates and nitrites, as ammonia,¹ and also in still smaller traces as organic nitrogen in the minute dust-particles which modern researches have revealed as being present in such enormous numbers in our atmosphere. What the sources of these nitrates and nitrites (which exist in quantities so minute that accurate determination of their amount is rendered extremely difficult) are is a disputed point. That nitrogen and oxygen unite together to form nitric and nitrous oxides under the influence of intense heat, such as the electric spark, has been proved beyond doubt. One source, therefore, is probably the electrical discharges which are taking place more or less frequently on different parts of the earth's surface. Nitrates may also be formed in the combustion of nitrogenous bodies.² In the burning of coal-gas, for example, it is probable that small quantities of nitrates may be produced. Similarly the slow combustion or decay of nitrogenous

¹ Although ammonia is more abundant than nitrates and nitrites, it only amounts to a few parts per million of air. According to Müntz, the air at great heights contains more ammonia than in its lower strata. The opposite, however, is the case with regard to nitrates, which are only found in air near the surface of the earth. See p. 49.

² Nitric acid may also be formed by the oxidation of ammonia by ozone, or peroxide of hydrogen.

organic matter, which constantly takes place all over the earth's surface, may be regarded as another source of this form of combined nitrogen. Ammonia may be similarly formed by the combustion, either quick or slow, of nitrogenous organic matter. It exists in the air as nitrate or nitrite of ammonia, and also as carbonate of ammonia.¹

Amount of combined Nitrogen falling in the Rain.

The importance of the combined nitrogen in the air as a source of soil-nitrogen is best gauged by the amount falling annually on the soil dissolved in rain. This has been found to vary considerably. In the rain falling in the vicinity of large towns the amount is greater than in rain falling in the country. Thus at Rothamsted, in England, the average amount for several years was only 3.37 lb. nitrogen per annum per acre, of which 2.53 lb. were as ammonia, .84 being as nitric acid. At Lincoln, in New Zealand, 1.74 lb. fell annually per acre—as ammonia, .74, as nitric acid, 1.00; while at Barbadoes the amount was 3.77 lb., of which .93 was as ammonia, and 2.84 as nitric acid.² That the combined nitrogen derived from the

¹ According to Schloesing, the chief source of the ammonia present in the air is the tropical ocean, which yields gradually to the atmosphere, under the action of the powerful evaporation constantly going on, a large amount of nitrogen in this form. The sources of the nitrogen of the ocean are the nitrates which it receives from the drainage of land, animal and vegetable matter, sewage, &c.

² See Appendix, Note I., p. 155.

air by the soil may be considerably in excess of this is highly probable. Soils, especially when damp, may absorb much larger quantities from the air of the combined nitrogen it contains. We must remember that the air in contact with the soil-surface is constantly being changed, and that there is thus a constant renewal of the air passed over the ground. The result is that the amount of air from which combined nitrogen may be removed is very great.¹

Nitrogen in the Soil.

It has been remarked as a fact worthy of notice that nitrogen is essentially a superficial element. By this is meant that it is only found, as a rule, on the earth's immediate surface. This statement can only be admitted to be true within certain limits. The chief source of nitrogen, in addition to the atmosphere, is, of course, vegetable and animal tissue.² As vegetable and animal tissue are only found to any extent on the earth's surface, nitrogen is therefore chiefly found there. The natural deposits of nitrogen salts, such as the nitrate-fields of Chili and the saltpetre

¹ To illustrate this point, it may be mentioned that on the least windy of days, when the wind is only moving at the rate of two miles an hour—and this, it may be added, is so slow as to be scarcely noticeable—the air in a space of 20 feet is changed over five hundred times in an hour. The combined nitrogen thus absorbed is probably entirely in the form of ammonia. It would seem so at any rate, from some experiments by Schloesing. See p. 132.

² No vegetable or animal cell exists which does not contain nitrogen.

soils of India, &c., also only occur superficially. Notwithstanding these facts, however, the amount of nitrogen which exists at probably considerable depths from the surface must be very great. There are few sedimentary rocks which do not contain it. At Rothamsted a sample of calcareous clay, taken from a depth of 500 feet, contained .04 per cent—that is, as much as is found, on an average, in the Rothamsted clay subsoils.

Nitrogen in the Subsoil.

On the whole, however, as we have said, nitrogen is chiefly found in the surface-soil. The amount found in the subsoil at Rothamsted seems to vary very slightly at different depths, the percentage amounting to from .06 to .03.¹ Unlike the nitrogen of the surface-soil, that in the subsoil seems to be of very ancient origin, being probably derived from the remains of animal and vegetable life in the mud deposited at the bottom of the ocean. It is more abundant in the case of a clay subsoil than in a sandy subsoil.

Nitrogen of Surface-Soil.

Nitrogen has a tendency to collect on the top layers of the surface-soil, the first 9 inches or foot containing

¹ This is less on the whole than what has been found in subsoils by Continental investigators. Thus, for example, A. Müller found the average of a number of analyses of subsoils to be .15 per cent., and the late Dr Anderson found the nitrogen in the subsoil of different Scottish wheat-soils to run from .15 per cent to .97 per cent.

by far the largest proportion of it. In the table given in the Appendix,¹ the rate at which it decreases in amount the further down we go is clearly shown. Determinations of the respective amounts of nitrogen in every 3 inches of the soil, taken to a depth of one foot of the experimental wheat-field at Rothamsted, showed that the percentage between the first 3 inches and the second 3 inches varied very slightly. A more marked difference, however, was shown to exist between the nitrogen in the second and third 3 inches ; while the fourth 3 inches were distinctly poorer—differing very little in their percentage of nitrogen from the subsoil. This was the case in unmanured soil. In the case of heavily manured soil, the increase in the soil's percentage, due to manure, was shown to be felt to the depth of a foot, but not much below it.²

A careful perusal of the tables in the Appendix will show that the quantity of nitrogen in the case of both arable and pasture soils steadily decreases for the first 3 feet, but that below this depth little decrease is seen, the percentage evidently becoming fairly constant.

¹ See Appendix, Note II., p. 156.

² “Under prolonged kitchen-garden culture the subsoil becomes enriched with nitrogenous matter to a far more considerable depth ; this has been shown by the analyses of the soil of the old kitchen-garden at Rothamsted. This is doubtless due to the practice of deep trenching employed by gardeners.”—R. Warington, ‘Lectures on Rothamsted Experiments.’ U.S.A. Bulletin, p. 24.

The amount of Nitrogen in the Soil.

Very considerable difference exists in the amount of nitrogen present in different soils. The majority of analyses refer only to the amount found in the surface-soil—generally in the first 9 or 12 inches. As the soil, further, is not a body exactly homogeneous in its character, very considerable difficulty exists in obtaining reliable results. A great deal depends, therefore, on the method of sampling and the basis of calculation adopted; and it may be that this may occasionally explain, to some extent at least, the great discrepancies in the estimation of the quantities of nitrogen present in different soils as found by different investigators.

Peat-soils richest in Nitrogen.

Of all soils, peat-soils are richest in nitrogen. Professor S. W. Johnson found the nitrogen in fifty separate samples of peat to range from .4 per cent to 2.9 per cent, the average being 1.5 per cent. On the other hand, marls and sandy soils are poorest, the analyses of a number of these soils showing only from .004 to .083 per cent for the former, and .025 to .074 for the latter. As a general rule most arable soils contain over one-tenth per cent of nitrogen, or, say, over 3500 lb. per acre. A good pasture-soil, taken to a depth of 9 inches at Rothamsted, was found to contain about a quarter per cent. In ten samples of soil, taken to a depth of 9 inches, from different parts of

Great Britain and Ireland, Munro found from .128 to .695 per cent of nitrogen, the average being .3278 per cent. The Rothamsted soils, it may be pointed out, are probably poor in nitrogen compared with most soils. A. Müller's investigations showed that in some of the soils he has analysed, the nitrogen amounted to little short of one per cent, while for the others the average was over half a per cent; even the poorer soils he examined contained about one quarter per cent on an average. Anderson's analyses of Scottish wheat-soils showed a variation of from .074 to .22 in the surface-soil, while he found in their subsoil from .15 to .92 per cent. Boussingault's results are also very much higher. The amount of nitrogen in a number of loams coming from widely different localities he examined contained from 6000 to 30,000 lb. per acre—the soil taken to a depth of 17 inches.¹

Nature of the Nitrogen in the Soil.

When we compare the amount of nitrogen removed by different crops (which, even in the case of those most exhaustive of nitrogen, does not often amount to more than 150 lb. per acre), with the amount contained in the soil, the former amount seems very insignificant when compared to the latter. Such being

¹ The comparatively insignificant effect the addition of various nitrogenous manures have in increasing the total soil-nitrogen is strikingly illustrated in the tables given in the Appendix, Note IV., p. 157.

the case, it would seem at first sight that the addition of nitrogen in the form of manures is quite superfluous. We must remember, however, that while the *total* amount of nitrogen is relatively large when compared to that removed by crops, only a very small proportion is in a condition *available* to the plant. This leads us to consider the different forms in which nitrogen is present in the soil, and their respective quantities.

Organic Nitrogen in the Soil.

Nitrogen occurs in the soil as organic nitrogen, nitric acid, nitrous acid, and ammonia. By far the largest proportion is present in the first of these forms. This is a wise provision, for otherwise the soil would be apt to become very speedily impoverished in nitrogen; for that present as nitrates it has scarcely any power to retain, while that present as ammonia is soon converted into nitrates by the process of *nitrification*.

The organic nitrogen of the soil, although we are apt to think of it as such, is by no means of a homogeneous character, or of equal value as a source of plant-food. Some of it, it would seem from recent investigations, is in a condition more susceptible of being converted into an available form than the rest. Thus in the process of nitrification, a process which we shall consider at length immediately, there seems to be generally a certain small proportion more ready to undergo this change than the rest; so that when this small amount

is used up nitrification proceeds more slowly. In short, although we as yet know very little of the nature of the organic nitrogen of soils, we cannot doubt but that there is a constant series of changes in its composition taking place, resulting in the gradual elaboration of more available forms, until ultimately these are converted into ammonia and nitrates.

The great bulk of the organic nitrogen, however, in the soil must be regarded as in an *inert* condition, and by no means available for the crop. What the exact chemical form of this nitrogen is it is extremely difficult to say. Mulder was of the opinion that a considerable proportion was in the form of humate of ammonia. This opinion, as we shall have occasion to see immediately, was based on false grounds. It is highly probable that it may be in some form approximating to amide nitrogen. Its inert character is against the belief that it long remains as albuminoid nitrogen.

Different Character of Surface and Subsoil Nitrogen.

A point of very considerable importance to notice is, that the nitrogenous organic matter of the surface-soil is very different from that found in the subsoil. This difference is shown by the variation in the ratio of nitrogen to carbon, which points to the fact that, just as we should naturally suppose, the origin of the latter is very much more ancient than the origin of the former. Thus in the first 9 inches of old pasture-

soil at Rothamsted, the ratio was 1:13; while in the subsoil, 3 feet from the surface, it was only 1:6. In the surface-soil it thus approaches more nearly in composition ordinary vegetable matter.

Nitrogen as Ammonia in Soils.

The second form in which nitrogen is present in soil is as ammonia. A very considerable misapprehension has existed in the past as to the amount of nitrogen in this form in soils. This mistake was due to the method adopted in estimating it, which consisted in treating the soil with boiling caustic alkalies and counting as ammonia what was given off as such. It is now known that certain forms of organic nitrogen—as, for example, amides—if treated in this way are slowly converted into ammonia. Statements, therefore, which are found in the older text-books, representing the amount of ammonia in soils as at over a tenth per cent, must be regarded as utterly unreliable. Indeed it is highly probable that ammonia only occurs in most soils in very minute traces. From what we know of the process of nitrification, we see how it is wellnigh impossible that ammonia should exist to any extent in the soil except under very exceptional circumstances.

Amount of Ammonia present in the Soil.

In ordinary soils it probably does not amount to more than from .0002 per cent to .0008 per cent, or

an average of .0006 per cent.¹ In rich soils, or in garden-soils, the amount may be considerably more. Thus Boussingault found in a garden-soil .002 per cent. In peat and in peat-mould even a higher percentage has been found—viz., .018 for the former and .05 for the latter.

Nitrogen present as Nitrates in the Soil.

The third form of nitrogen in the soil is nitric acid. It is more abundant in this form than as ammonia; but still, compared with the organic nitrogen, its amount is trifling. Probably not more than 5 per cent of the total nitrogen of a soil is ever present as nitrates. The reason of this is twofold. First, as we have already remarked, the soil has very little power to retain nitrogen in this form; and secondly, where the soil is covered with growing vegetation the nitrates are quickly assimilated by the plant as they are formed. It is for this reason that we find the quantity of nitrogen as nitrates very much greater in fallow soils than in those covered with a crop.

Position of Nitric Nitrogen in Soil.

As we shall have occasion to see more fully in the following chapter on Nitrification, the formation of nitrates is chiefly limited to the surface-soil, the largest proportion being formed within the first 9 or 12 inches. For this reason we find the largest quantity

¹ See Storer's Agric. Chem., vol. i. p. 357.

of nitrates in the surface-soil. But inasmuch as they are easily washed into the lower layers of the soil after formation, we often find a considerable proportion beyond the first 9 inches. The position of nitrates in the soil thus depends very considerably on the season of the year and the weather. In dry weather, where the evaporation of the soil-water takes place at a considerable rate, the tendency will be to concentrate the nitrates in the superficial portion of the soil. In wet weather, on the other hand, the tendency will be to wash the nitrates into the lower layers.

Amount of Nitrates in the Soil.

The determination of the amount of nitrates in a soil is not of very great economic importance; as this varies so much, and depends on such a number of different conditions, such as the season, the condition of the land, and prevailing weather. A point of very much greater economic importance is the total amount formed in the year, and the rate at which nitrification takes place. These questions will be discussed elsewhere, and therefore need not here be referred to. Some interesting analyses made at Rothamsted, however, of the amount of nitrates in soils at different depths, merit careful consideration.

Nitrates in Fallow Soils.

In the Appendix to the chapter on Nitrification,¹

¹ See Chapter IV., Appendix, Note VII., p. 198.

will be found a table containing the amounts of nitrates found in the first 27 inches of fallow soils. The amounts vary from 33.7 lb. to 59.9 lb. per acre. The analyses were made in September or October. In four out of the six analyses, it will be found that by far the largest proportion is found in the first 9 inches. In these cases the preceding summer had been dry, and thus the nitrates had not been washed down to any depth. In the other two cases the largest amount is found in the second 9 inches of soil, and a considerable amount is also found in the third 9 inches.

Nitrates in Cropped Soils.

In the case of cropped soils we find the amount of nitrates very much less. A table containing an elaborate series of determinations of nitrates in cropped soils, receiving, however, no manure, and taken to a depth of 9 feet, will be found in the Appendix.¹ The first 27 inches only contain some 5 to 14 lb. per acre, and the most of that is found in the first 9 inches. This shows how speedily nitrates are assimilated by the growing crop. An interesting point shown by these analyses is that nitrates almost entirely cease in cropped soils a certain depth down; but that at a still lower depth they again occur in small quantities.

¹ See Appendix, Note III., p. 157.

Nitrates in manured Wheat-soils.

Lastly, we give in the Appendix¹ the amount of nitrates found in wheat and barley soils, differently manured, at Rothamsted. From a perusal of these tables, it will be seen that the amount (under various conditions of manuring) of nitrates in the first 27 inches varies from 21.2 lb. per acre to 52.2 lb. for the wheat-soils, and 20.1 to 44.1 lb. per acre for the barley-soils.

THE SOURCES OF SOIL-NITROGEN.

We shall now consider the sources of soil-nitrogen, the conditions which determine its increase, and the amount of that increase, as well as the sources of loss, and the conditions which determine this loss.

That dissolved in Rain.

The natural sources of the soil-nitrogen are several. We have first of all the atmospheric nitrogen. Of this let us first consider that present as combined nitrogen. This, as we have already seen, consists chiefly of nitrates, nitrites, and ammonia, and reaches the soil dissolved in rain or in other meteoric forms of water, such as snow, hail, fog, hoar-frost, &c.

That absorbed by the Soil from the Air.

It is also absorbed by the soil from the air, especially when the soil is in a damp condition, as has been

¹ See Appendix, Note IV., p. 157.

proved by Schloesing's experiments, already referred to. The total amount which falls dissolved in the rain, per acre per annum, varies very considerably in different parts of the world, but in any case only amounts yearly to a few pounds per acre.¹ That absorbed by the soil from the air may be probably very much more considerable. Schloesing in his experiments found that this latter might amount to 38 lb. per acre per annum. These results, however, were obtained under circumstances most favourable for absorption—viz., with a damp soil and in the vicinity of Paris, where the air is presumably richer in combined nitrogen than it is in the country. The nitrogen absorbed, it may be mentioned, was almost entirely in the form of ammonia. It is to be noted that the nitrogen the soil obtains in this way from the combined nitrogen of the air is not all pure gain. With regard to the nitrates and nitrites, no doubt most of these are formed by electrical discharge, although a small portion of them may be formed by the oxidation of ammonia by means of ozone and peroxide of hydrogen. With regard to the ammonia and the combined nitrogen present in the organic particles in the air, a not inconsiderable proportion is probably derived from the soil. Schloesing considers the chief source of the ammonia present in the air to be the tropical ocean; but we must remember that the source of much of the nitrogen in the tropical ocean is, after all, the soil.

¹ See Appendix, Note I., p. 155.

Leaving aside for a moment the question of the availability of the free nitrogen of the air, let us consider the other sources of soil-nitrogen.

Accumulation of Soil-nitrogen under Natural Conditions.

The chief source is of course the remains of vegetable and animal tissue.¹ Plants are the great conservers of soil-nitrogen. By assimilating such available forms of it as nitrates, and converting them into organic nitrogen, they prevent the loss of this most valuable of all soil constituents that would otherwise take place.

They also serve to collect the nitrogen from the lower soil-layers and concentrate it in the surface portion. In a state of nature, where the soil is constantly covered with vegetation, the process going on, therefore, will be one of steady accumulation of nitrogen in the surface-soil. To what extent this accumulation goes on, and how far it is limited by the conditions of loss, will be considered immediately. That it may go on to a very great extent is amply proved by the existence of the so-called *virgin* soils

¹ The original source of the nitrogen in the soil must have been the nitrogen in the air. When plants first begin to grow on a purely mineral soil, they must obtain nitrogen from some source. The small traces washed down in the rain will supply sufficient nitrogen to enable a scanty growth of the lower forms of vegetable life; whereas these by their decay furnish their successors with a more abundant source, which rapidly increases, until we have a fair percentage of humus accumulated.

of countries like America and Australia. There are cases, also, where the accumulation of nitrogen is practically unlimited, although the result in such cases is not necessarily a fertile soil. Such cases are peat-bogs. But let us pass on to the accumulation of soil-nitrogen under the ordinary conditions of husbandry.

Accumulation of Nitrogen in Pastures.

The case which, under the conditions of ordinary farming, most resembles a state of nature, is that of permanent pasture. It will be best, therefore, to study first the conditions under which gain of nitrogen takes place in this case.

Increase of Nitrogen in the soil of Pasture-land.

That there is a steady increase of nitrogen in the soil of land under pasture is a fact of universal experience. The older a pasture is the richer is its soil in nitrogen. The comparison of the analyses of the soil of arable land with the soil of pastures of different ages shows this in a striking way.¹ Thus at Rothamsted it was found that while the amount of nitrogen in an ordinary arable soil was .140 per cent, that in pastures eight, eighteen, twenty-one, and thirty years old was respectively .151, .174, .204, and .241 per cent. In the last two analyses we have a record of the actual gain in nitrogen made by the

¹ See Appendix, Note V., p. 158.

same pasture, this being .04 per cent in nine years' time. From these statistics it may be inferred that the surface-soil of a pasture may increase at the rate of 50 lb. per acre per annum. A point of great interest in connection with this subject is the fact that there seems to be a limit to the accumulation of nitrogen in pastures; for it would seem that pastures centuries old are not any richer in nitrogen than those thirty to forty years old.

Gain of Nitrogen with Leguminous Crops.

Another case where the gain of nitrogen to the surface-soil is very striking is in that of leguminous crops, such as clover, beans, peas, &c. This fact has been long recognised—especially with regard to clover—by farmers, and has been largely instrumental in leading to the investigation of the “free” nitrogen question. That a soil bearing a leguminous crop increases in nitrogen at a very striking rate is a problem that requires to be solved. A partial explanation of the phenomenon is found in the extraordinary capacity such a crop as clover has, by means of its multitudinous and ramifying roots, for collecting nitrogen from the subsoil. This, however, would only account for the increase in nitrogen to a certain extent. There must be some other source, and the only other source is the air. That the free nitrogen of the air is, after all, available for the plant's needs, is a supposition which has long seemed extremely prob-

able, and which, within the last few years, has been proved beyond doubt to be a fact in the case of leguminous plants.

The Fixation of "Free" Nitrogen.

The method in which these plants are able to make use of the free nitrogen is still a point requiring much research. So far as the question is at present investigated, it would seem that the fixation is effected by means of micro-organisms present in tubercles or root excrescences found on the roots of leguminous plants.¹ Not merely has this been placed beyond doubt, but attempts have been made to isolate and study the bacteria effecting this fixation. From Nobbe's exceedingly interesting experiments, recently carried out, it would seem that the different kinds of leguminous plants have different bacteria. Thus the bacteria in the tubercle on the pea seems to be of a different order from the bacteria in the tubercles of the lupin, and so on. This discovery is of great importance, it need scarcely be pointed out, as it throws much light on the principles of the rotation of crops.

Influence of Manures in increasing Soil-nitrogen.

It may be doubted, however, if under any other conditions there is a positive gain of soil-nitrogen. In other cases the amount in the soil is only *maintained* under liberal manuring. In connection with

¹ See Historical Introduction, pp. 40-45.

this point a very striking fact has been observed with regard to the effect of continuous large applications of farmyard manure. It has been found at Rothamsted that in such a case, after a while, the manure does not seem to increase the soil-nitrogen, although where the nitrogen goes to remains a mystery. In the case of the application of artificial manures, there does not seem to be almost any appreciable gain to the soil-nitrogen. The soil-nitrogen is only increased by means of the residue of crops. In this way, of course, by increasing the amount of this crop-residue, artificial manures may be said indirectly to increase the soil-nitrogen.¹

SOURCES OF LOSS OF NITROGEN.

We now come to consider the sources of loss. The chief source, of course, is that by drainage. Land under cultivation will suffer very much more from this source of loss than in a state of nature. Our modern system of husbandry, involving as it does thorough drainage, can scarcely fail to very considerably increase this source of loss.

Loss of Nitrates by Drainage.

The form in which nitrogen is lost in this way is as nitrates. It is a somewhat striking fact, and one

¹ The evidence demonstrating this is to be found in the fact that the amount of carbon found in different soils rises or falls in proportion to the nitrogen. See p. 126.

worthy of note, that of the three important manurial ingredients—nitrogen, phosphoric acid, and potash, the first of these, in its final and most valuable form, is alone incapable of being fixed by the soil, and thus retained from loss by drainage.

As nitrates are constantly being formed in the soil, the loss to its total nitrogen must be considerable. It is due to the fact of the great solubility of nitrates, as well as to the fact, as already mentioned, of the incapacity of the soil-particles to fix them. To this one exception must be made. According to Knop, small quantities of nitric acid are held in the *insoluble* condition in soils in the form of highly *basic nitrates of iron and alumina*. The quantity, however, of these insoluble compounds probably amounts to a very minute trace indeed.

Permanent Pasture and "Catch-cropping"
prevents Loss.

The amount of loss varies, and will depend on a number of different circumstances—thus the nature of the soil, climate, and season of the year will all influence its quantity. The way in which the soil is cultivated is also another important factor. Where it is constantly covered with vegetation, as in the case of permanent pasture, the loss will be at a minimum. Under such conditions, plant-roots are always there ready to fix, in the insoluble organic form, the soluble nitrates as they are formed. A consideration of this

fact forms one of the strongest arguments in favour of the practice of what is known as "catch-cropping." The practice consists in sowing some quickly-growing green crop—*e.g.*, *mustard*, *vetches*, &c.—so as to occupy the soil immediately after harvest, and subsequently to plough it in. The nitrates, which it is known are most abundantly formed towards the end of summer,¹ and which are allowed to accumulate in the soil from the period at which the active growth of, and consequently assimilation of nitrates by, the cereal crop have ceased, are thus fixed in the organic matter of the plant, and removed from danger of loss by drainage incidental to autumn rains.

Other Conditions diminishing Loss of Nitrates.

The nature of the soil is another important condition regulating this loss. Some soils are very much opener and more porous than others; in such soils, of course, the loss by drainage will be greatest. We are apt at first sight, however, knowing the great solubility of nitrates, to overrate this source of loss. We have to remember that while nitrates are constantly being washed down to the lower layers of the soil, there is likewise an upward compensating movement of the soil-water constantly taking place. This is due to the evaporation of water from the surface of the soil, which induces an upward capillary move-

¹ See Chapter IV. on Nitrification.

ment of water from its lower to its higher layers.¹ This upward movement of water is very much increased, in the case of soil covered with vegetation, by the transpiration of the plants. The climate and the season of the year will affect the extent of this upward movement. Where there is a heavy rainfall it will be very much less than in dry climates. After a long period of drought the nitrates will be found to be concentrated in the top few inches of the soil; and in hot climates this sometimes takes place to such an extent that the surface of the soil has been actually covered with a saline crust, caused by the rapid evaporation of soil-water under the influence of a burning tropical sun. From this point of view it will be seen how very much less powerful a single shower of rain is—even although at the time it is heavy—in causing loss of nitrates by drainage, than a continuance of wet weather. In the former case, where the showers are separated by an interval of dry weather, the nitrates washed down into the lower layers of the soil are slowly brought up again by the capillary action caused by evaporation.

Amount of Loss by Drainage.

What the actual amount of loss is which takes place in this way it is wellnigh impossible to say. What it amounts to under certain definite circum-

¹ Diffusion as well as capillary attraction is a means of bringing nitrates again to the surface-soil after rain.

stances has been discovered by actual experiment at Rothamsted. Taking the circumstances most favourable to extreme loss—viz., unmanured fallow land—the highest amount registered at Rothamsted for a year is 54.2 lb. per acre from soil 20 inches deep, while the smallest amount is 20.9 lb. In the former case, the drainage-water was equivalent to 21.66 inches, while in the latter, to 8.96 inches. The average for thirteen years on unmanured fallow soil has been 37.3 lb. (for 20 inches), 32.6 lb. (for 40 inches), 35.6 lb. (for 60 inches). The point of especial interest in this connection is that an annual loss of nitrogen, equal to over 2 cwt. of nitrate of soda, may take place from a comparatively poor arable soil lying fallow.

The loss on cropped soils is of course very much less—in short, should amount to very little—especially in permanent pasture, where it is reduced to a minimum. Taking an average, Mr Warington is of opinion that the loss in England may be put at 8 lb. per annum per acre.¹

Loss in Form of Free Nitrogen.

The other chief natural source of loss of nitrogen is due to its escape from the soil in its “free” state. This source of loss is very much less important than that by drainage, and probably amounts to very little.

¹ See Appendix, Note VI., p. 158, and Note VIII., p. 160; also p. 154.

That, however, it takes place is beyond a doubt; and that it may—as we shall see by-and-by—under certain circumstances amount to something very considerable is also proved. Where large quantities of nitrogenous organic matter decay, and where, consequently, the supply of atmospheric oxygen is insufficient to effect complete oxidation, “free” nitrogen may be evolved in considerable quantities. Similarly, it may be evolved in the case of vegetable matter decaying under water. In soils rich in organic matter the reduction of even nitrates may take place, accompanied with the evolution of free nitrogen, which is thus lost.

Total Amount of Loss of Nitrogen.

What the rate of total loss of nitrogen is from these different sources does not admit of easy calculation. Sir John Lawes, in dealing with the question of soil-fertility, estimated some years ago, by comparing the soil of old pasture at Rothamsted with that which had been under arable culture for 250 years, that during that period some 3000 lb. of nitrogen per acre had disappeared from the arable land. Examples of decrease of nitrogen in Rothamsted soils, under various conditions of culture, will be found in the Appendix.¹

Loss of Nitrogen by Retrogression.

A source of loss of nitrogen may be here men-

¹ See Appendix, Note VII., p. 159.

tioned which has to do with diminution of amount of available nitrogen, rather than absolute loss of nitrogen to the soil, and which we may term *loss by retrogression*. Nitrogen in an available form, such as nitrates, has been found to be converted into a less available form. This retrogression may be effected, as in the case of nitrates, by reduction—*i.e.*, by removal of the oxygen in combination with the nitrogen, which in many cases may be set free, and thus partially although not necessarily entirely lost. Such reduction is due to the action of bacteria of the denitrifying order.¹ Or, on the other hand, nitrogen may be converted into some kind of insoluble form which seems to resist decomposition, and lies in an inert condition in the soil utterly unavailable for the plants' needs. A striking example of this retrogression of nitrogen seems to be afforded in the case of farmyard manure. It has been found in the Rothamsted experiments, as has been pointed out in the preceding pages, that when farmyard manure is applied, year after year, to the same land in large quantities, a very considerable percentage of its nitrogen does not (*i.e.*, within a reasonable number of years) become available for the crop's uses. What, indeed, becomes of the nitrogen is a mystery; but it is highly probable that some such kind of retrogression as that above referred to, whereby the nitrogen is converted into some inert organic form, takes place.

¹ See following Chapter on Nitrification, p. 178.

Artificial Sources of Loss of Nitrogen.

So far, the sources of loss of nitrogen considered have been what we may term *natural* sources. By this is meant that the loss of nitrogen from the above sources takes place in a state of nature, and not merely under conditions of cultivation. No doubt the loss due to drainage is very much greater under arable farming than would be the case where artificial drainage does not obtain; still, under any conditions, this loss must be reckoned with. On the other hand, by *artificial* sources of loss are meant those entirely dependent on our modern system of agriculture and our modern system of sewage disposal, whereby the nitrogen contained in that portion of the produce of the farm which goes to supply our food is not returned to the soil, but is totally lost.

Amount of Nitrogen removed in Crops.

The modern tendency towards centralisation in large towns has rendered this loss—despite all that has been said to the contrary—a necessity. It is extremely difficult, however, to form any estimate of its amount. We know, of course, the amount of nitrogen removed from the soil by different crops. We cannot, however, estimate how much of this may find its way back again to the soil. The amount of nitrogen contained in the different crops will be fully dealt with in the chapter on the manuring of different crops.

It may be, however, not without interest to give here some approximate indication of the amount of this loss, in order to render the view of the subject as comprehensive as possible.

Recent agricultural returns for Great Britain give the total produce of *wheat* at over 76 million bushels, that of *barley* at over 69 million, and that of *oats* at over 150 million. Calculating the amount of nitrogen, these quantities of wheat, barley, and oats respectively and collectively contain, and calculating also how much *sulphate of ammonia* and *nitrate of soda* these amounts of nitrogen represent, the following are the results:—

	Bushels.	Nitrogen. Tons.	Sulphate of Ammonia. Tons.	Nitrate of Soda. Tons.
Wheat . .	76,224,940	37,432	176,465	227,266
Barley . .	69,948,266	27,324	128,813	165,896
Oats . .	150,789,416	56,835	267,936	345,068
Total . .	<u>296,962,622</u>	<u>121,591</u>	<u>573,214</u>	<u>738,230</u>

Of course these figures, so far as the amounts of nitrogen are concerned, can only be regarded as approximate, as it is only possible in such calculations to obtain approximate results. Accepting these calculations as merely approximate, they are, nevertheless, of the highest interest and importance. It is of great importance to understand that in the annual produce of our three common cereal crops—supposing them to be all consumed off the farm—there is removed from the soil a quantity of nitrogen equal to that contained in over *half a million tons of sulphate*

of ammonia, and three quarters of a million tons of nitrate of soda.

As has already been remarked, it is impossible to estimate exactly what proportion of this total nitrogen finds its way back to the soil. In the case of wheat, it may be pointed out that the portion which is used as a feeding-stuff—viz., *bran*—is very much richer in nitrogen than the flour. While, then, we are unable to estimate with any exactitude this source of loss of nitrogen, it cannot for a moment be doubted that it is enormous, from what has been already stated. We must remember that the portion of the crop richest in nitrogen is that which is generally removed—the straw which is grown in producing a bushel of wheat, barley, or oats, containing less than half the amount of nitrogen contained by a bushel of the grain itself.

Losses of Nitrogen incurred on the Farm.

In addition to the loss due to removal of crops from the farm, there are one or two other sources of loss which it may be well to briefly refer to.

Loss in Treatment of Farmyard Manure.

There can be little doubt that in the past a very considerable source of loss was the improper treatment of farmyard manure. The way in which this loss may take place will be fully considered in the chapter on farmyard manure. Suffice it to say here, that this may take place by volatilisation of the nitrogen as

carbonate of ammonia, caused by carelessness in allowing the temperature of the manure-heap to rise too high; or by drainage of the soluble nitrogen compounds, caused by allowing the rich black liquor of the manure-heap to be washed away, and not properly conserved.

Nitrogen removed in Milk.

Another source of loss which is apt to be overlooked is the amount of nitrogen removed in milk. Professor Storer has calculated that in the case of a cow giving 2000 quarts, or 4300 lb., of milk in a year, and the milk being all sold as such, there would be carried away from the farm 22 lb. of nitrogen.¹

Economics of the Nitrogen question.

And here, before concluding our survey of the different sources of loss of nitrogen, it may be well to regard for a moment the subject from a somewhat wider standpoint than that from which we have been considering it. The total supply of nitrogen in a combined form is limited. As we have pointed out, it may be regarded as the element on which, more than any other, life, animal as well as vegetable, depends. To animal life it is alone available in combined form; to vegetable life it is chiefly also only

¹ According to the Agricultural Returns for 1888, the number of cows in milk in Great Britain amounted to 2,450,444. If we multiply this number by 22 the result is 54,000,000 lb., or in tons 24,107. This quantity represents 154,067 tons of ordinary commercial nitrate of soda.

available in combined form. In the air we have an unlimited quantity of nitrogen, but it is almost entirely in an *uncombined* form, and therefore largely unavailable. The conversion of nitrogen from the free state to a combined form is a process which takes place only very slowly. Any source which diminishes the sum-total of our already all too limited supply of combined nitrogen must be regarded as worthy of most serious consideration. The question, therefore, of the artificial waste of nitrogen daily taking place around us, is one which ought to possess for economists a very great interest indeed. This waste has, of late years, enormously increased, and would seem to threaten us at no very distant date with a nitrogen famine. It is incidental to the use of certain nitrogenous substances in the manufacture of various articles, and to our present system of sewage disposal.

Loss of Nitrogen-compounds in the Arts.

The articles referred to are such as explosives, starch, textile substances, malt liquors, &c. The question is strikingly dealt with in an able paper on "The Economy of Nitrogen" in the 'Quarterly Journal of Science.'¹

Loss due to Use of Gunpowder.

The explosives—more particularly gunpowder—are the most important of these articles. Gunpowder

¹ For 1878 (p. 146 *et seq.*) The reader interested in the subject is referred to the paper itself.

contains 75 per cent of saltpetre, which in its turn contains about 10 per cent of nitrogen. When gunpowder explodes, practically the whole of this nitrogen is converted into "free" nitrogen. The loss is thus in a sense irreparable. In the paper above referred to, our total annual exports of this substance are estimated at 19,000,000 lb.; while the total annual production of the world is estimated at not less than 100,000,000 lb. The annual loss of nitrogen due to this source alone would amount to about 10,000,000 lb.¹ Similarly, loss of nitrogen, although to a less extent, is caused by the use of other explosives, as well as in the manufacture of the other articles above mentioned.

Loss due to Sewage Disposal.

The loss due to our present system of sewage disposal has been already taken into account in dealing with the loss due to removal of crops. It may be well, however, to treat it from the sewage aspect. Taking the amount of nitrogen in the excreta of every individual as, on an average, half an ounce, the annual amount voided in the excreta of the total population of the British Isles would amount to 365,000,000 lb.²—of this, the amount in the London sewage alone being 91,000,000 lb.³ By the water system, which is almost

¹ In tons 4464, and represents 28,530 tons of nitrate of soda.

² This in tons 162,946, which represents 1,041,384 tons of nitrate of soda.

³ This in tons 40,625, which represents 259,633 tons of nitrate of soda. See paper in 'Journal of Science' already referred to.

universally adopted in this country, the above quantity of nitrogen is entirely lost to the soil. A small portion of it, it may be argued, is eventually recovered in seaweed and fish, which may be used for manure. This, however, is to argue too much *sub specie æternitatis*. Not all the nitrogen originally present in the excreta finds its way into the sea; for it is highly probable that a considerable quantity escapes in the process of the decomposition of the sewage as “free” nitrogen.

From the above statement of the sources of loss and gain of nitrogen taking place in the soil, it may be pretty safe to conclude that while in a state of nature the gain balances the loss, if indeed it does not do more, under conditions of arable farming such is very far from being the case; and that if fertility of the land is to be maintained, recourse to nitrogenous manures must be had,—in short, that the application of artificial nitrogenous manures is a necessary condition of modern husbandry.

Our Artificial Nitrogen Supply.

Before concluding this chapter, it may be interesting to enumerate very briefly the chief sources of our artificial nitrogen supply.

Nitrate of Soda and Sulphate of Ammonia.

The most important artificial nitrogenous manures in use at present are nitrate of soda and sulphate of ammonia. Of the former, the annual exportation from

Chili is close on one million tons, of which quantity about 120,000 tons is imported into the United Kingdom. Of sulphate of ammonia, on the other hand, the total production in this country is about 130,000 tons per annum,¹ the greater proportion of which is exported, leaving only from 30,000 to 40,000 tons for consumption. Nitrate of soda, it must be remembered, is not entirely used for manurial purposes, a small proportion of the above imports being used for chemical manufacturing purposes.

Peruvian Guano.

Peruvian guano is another important nitrogenous manure very much less abundant now than formerly, as the different guano-beds have become nearly exhausted. While the imports of this important manure into the United Kingdom amounted in 1870 to nearly 250,000 tons, at present not more than 11,000 tons are being imported.

Bones.

A further source of nitrogen is bones, which, of course, are chiefly valuable as a phosphatic manure, but which contain also some 3 to 4 per cent of nitrogen. Of this valuable manure we import at present about 30,000 tons, while about 60,000 tons are collected in this country, bringing up our total consumption to 100,000 tons.

¹ Europe's total production may be stated at 200,000 tons.

Other Nitrogenous Manures.

The above mentioned are the most important of nitrogenous manures; there are, however, a number of other nitrogenous manures used in this country in very much smaller quantities. As most of these substances are made in this country, it is very difficult to estimate the amount of their annual production with exactness. These substances are as follows: fish-guano, meat-meal guano, dried blood, shoddy, scutch, horns and hoofs, hair, bristles, feathers, leather-scrap, &c. Of fish-guano, the total consumption per annum may be put down at about 8000 tons, of which a fourth is imported into this country, the remaining 6000 tons being manufactured at home. Of meat-meal guano, dried blood, hoof-guano, &c., about 2500 tons are annually imported, the home production bringing up the total amount to some 10,000 tons. Of shoddy, some 12,000 tons are manufactured in this country; while scutch—the name given to a manure manufactured from the waste products incidental to the manufacture of glue and the dressing of skins—is produced only to the extent of a few thousand tons annually.

It is a fact worthy of notice, that while the use of phosphatic manures has increased very considerably of late years, the same cannot be said of nitrogen. According to Mr Hermann Voss, some 34,000¹ tons

¹ 10,500 tons of which were as guano.

of nitrogen were used in the form of artificial manures in 1873, while now only about 28,000 tons are used—*i.e.*, some 6000 tons less.

Oil-seeds and Oilcakes.

There still remains a very important source of nitrogen which has not yet been mentioned, in the shape of oil-seeds and oilcakes, used for feeding purposes. Oilcakes are both manufactured in this country and imported in large quantities. Recent Agricultural Returns show the total imports of oilcakes at 256,296 tons; that of linseed at 370,000 tons; that of rape-seed at 80,000 tons; and that of cotton-seed at 289,413 tons.

Other imported Sources of Nitrogen.

We have further, in considering this question, to take into account the large amount of maize, peas, beans, wheat, and oats which are imported into this country, a certain quantity of which is used as cattle-food, and will therefore go to enrich their manure. Also the imported straw used for purposes of litter must not be forgotten. In 1887 this amounted to 52,393 tons.

Conclusion.

In conclusion, it may be asked how far are the artificial sources of nitrogen able to make good the loss? In the opinion of such a reliable authority as

Sir John Lawes, they do not. There are some soils which depend almost entirely upon imported fertility, and could not be cultivated without it. Upon some of them it is possible that the imports of nitrogen are in excess of the exports. Taking the agricultural acreage as a whole, however, he is of opinion that there is a decided loss of nitrogen, which he estimates at *from 15 lb. to 20 lb. per acre per annum.*¹

¹ Mr Warington estimates this at about 8 lb. See p. 141.

APPENDIX TO CHAPTER III.

NOTE I. (p. 119).

DETERMINATIONS OF THE QUANTITY OF NITROGEN SUPPLIED
BY RAIN, AS AMMONIA AND NITRIC ACID, TO AN ACRE
OF LAND, DURING ONE YEAR.

(From Dr Fream's '*Soils and their Properties*,' p. 62.)

	Year.	Rain- fall.	Nitrogen per million, as		Total Nitrogen per acre.
			Am- monia.	Nitric Acid.	
					lb.
Kuschen	1864-65	11.85	0.54	0.16	1.86
"	1865-66	17.70	0.44	0.16	2.50
Insterburg	1864-65	27.55	0.55	0.30	5.49
"	1865-66	23.79	0.76	0.49	6.81
Dahme	1865	17.09	1.42	0.30	6.66
Regenwalde	1864-65	23.48	2.03	0.80	15.09
"	1865-66	19.31	1.88	0.48	10.38
"	1866-67	25.37	2.28	0.56	16.44
Ida-Marienhütte, mean of six years	1865-70	22.65	..	..	9.92
Proskau	1864-65	17.81	3.21	1.73	20.91
Florence	1870	36.55	1.17	0.44	13.36
"	1871	42.48	0.81	0.22	9.89
"	1872	50.82	0.82	0.26	12.51
Vallombrosa	1872	79.83	0.42	0.15	10.38
Montsouris, Paris	1877-78	23.62	1.91	0.24	11.54
"	1878-79	25.79	1.20	0.70	11.16
"	1879-80	15.70	1.36	1.60	10.52
	Mean of 22 years	27.63	..	..	10.23

NOTE II. (p. 122).

NITROGEN IN SOILS AT VARIOUS DEPTHS.

(1) *Rothamsted Soils.*

Depth.	Arable soil.		Old pasture soil.	
	per cent.	lb. per acre.	per cent.	lb. per acre.
1st 9 inches . .	0.120	3,015	0.245	5,351
2d 9 " . .	0.068	1,629	0.082	2,313
3d 9 " . .	0.059	1,461	0.053	1,580
4th 9 " . .	0.051	1,228	0.046	1,412
5th 9 " . .	0.045	1,090	0.042	1,301
6th 9 " . .	0.044	1,131	0.039	1,186
Total, 54 inches	...	9,554	...	13,143
7th 9 inches . .	0.042	1,049	...	...
8th 9 " . .	0.041	1,095	...	...
9th 9 " . .	0.044	1,173	...	...
10th 9 " . .	0.043	1,076	...	...
11th 9 " . .	0.043	1,112	...	...
12th 9 " . .	0.045	1,198	...	...
Total, 9 feet .	...	16,257	...	...

(2) *Manitoba Soils.*

Depth.	Brandon.	Niverville.	Winnipeg.	Selkirk.
	per cent.	per cent.	per cent.	per cent.
1st foot	0.187	0.261	0.428	0.618
2d "	0.109	0.169	0.327	0.264
3d "	0.072	0.069	0.158	0.076
4th "	0.019	0.038	0.107	0.042

NOTE III. (p. 130).

NITROGEN AS NITRATES IN CROPPED SOILS RECEIVING NO NITROGENOUS MANURE, IN LB. PER ACRE (*Rothamsted Soils*).

Depth.	Wheat.		Bokhara clover, 1882.	Vetches, 1883.	Lucern, 1885.	White clover, 1885.
	After fallow, 1883.	After clover, 1883.				
	lb.	lb.	lb.	lb.	lb.	lb.
1st 9 inches .	3.4	6.1	3.4	10.2	8.9	11.5
2d 9 " .	3.1	4.4	1.0	2.7	1.1	1.4
3d 9 " .	0.8	1.6	0.6	1.1	0.8	0.9
4th 9 " .	1.0	1.3	1.0	1.5	0.8	1.9
5th 9 " .	0.8	1.5	0.8	2.5	1.0	7.1
6th 9 " .	0.6	0.8	1.7	4.4	0.9	11.3
7th 9 " .	0.8	2.2	...	4.5	0.6	13.1
8th 9 " .	0.9	1.7	...	4.9	0.8	12.6
9th 9 " .	0.7	2.4	...	4.8	0.7	11.2
10th 9 " .	2.0	2.1	...	5.1	0.6	10.7
11th 9 " .	1.5	2.1	...	6.4	0.4	11.1
12th 9 " .	3.8	2.8	...	6.5	0.4	10.0

NOTE IV. (p. 124 and p. 131).

NITROGEN AS NITRATES IN WHEAT-SOILS VARIOUSLY MANURED, OCTOBER 1881, IN LB. PER ACRE (*Rothamsted Soils*).

Plot.	Manuring.	1st 9 inches.	2d 9 inches.	3d 9 inches.	Total 27 inches.	Excess over plots 3 and 4.
		lb.	lb.	lb.	lb.	lb.
3	No manure, 38 years	9.7	5.3	2.8	17.8	..
4	" 30 "	9.2	4.0	1.8	15.0	..
16a	" 17 "	10.6	5.0	2.3	17.9	1.5
5a	Ash constituents, 30 years . . .	12.6	7.1	4.6	24.3	7.9
17a	" " 1 year	10.3	7.5	3.4	21.2	4.8
6a	" and ammonium salts, 200 lb. .	16.5	7.5	4.7	28.7	12.3
7a	" " 400 "	22.8	11.3	5.7	39.8	23.4
8a	" " 600 "	21.1	13.9	7.8	42.8	26.4
9a	Ash and sodium nitrate, 550 " .	19.7	10.0	8.2	37.9	21.5
9b	Sodium nitrate, " "	16.3	20.1	17.7	54.1	37.7
10a	Ammonium salts, 100 "	14.2	11.9	7.3	33.4	17.0
11a	Superphosphate and ammonium salts, 400 lb.	17.9	9.3	3.6	30.8	14.4
19	Rape-cake, 1700 lb.	14.1	13.0	7.1	34.2	17.8
2	Farmyard manure, 14 tons—38 years .	30.0	15.4	6.8	52.2	35.8

NITROGEN AS NITRATES IN BARLEY-SOILS VARIOUSLY MANURED,
MARCH 1892, IN LB. PER ACRE (*Rothamsted Soils*).

Plot.	Manuring.	1st 9 inches.	2d 9 inches.	3d 9 inches.	Total 27 inches.	Excess over plot 10.
		lb.	lb.	lb.	lb.	lb.
10	No manure	5.9	4.7	5.1	15.7	..
20-40	Ash constituents (mean) . . .	6.7	7.0	6.4	20.1	4.4
1 A	Ammonium salts, 200 lb. . .	6.1	8.3	7.0	21.4	5.7
2 A-4 A	" and ash constituents (mean) . . .	7.7	7.8	7.6	23.1	7.4
1 AA	Sodium nitrate, 275 lb. . .	9.7	6.8	9.0	25.5	9.8
2 AA-4 AA	" and ash constituents (mean) . . .	8.3	7.4	7.5	23.2	7.5
1 C	Rape-cake, 1000 lb.	10.6	13.7	7.9	32.2	16.5
2 C-4 C	" and ash constituents (mean) . . .	8.8	11.9	8.7	29.4	13.7
7 ¹	No manure, 10 years—formerly dung	14.8	11.8	10.9	37.5	21.8
7 ²	Farmyard manure, 14 tons . .	18.6	14.6	10.9	44.1	28.4

NOTE V. (p. 134).

EXAMPLES OF INCREASE OF NITROGEN IN ROTHAMSTED SOILS
LAID DOWN IN PASTURE.

	Age of pasture.	Nitrogen in 1st 9 inches.
	Years.	Per cent.
Arable land . . . . .	...	0.140
Barn-field pasture	8	0.151
Apple-tree pasture	18	0.174
Dr Gilbert's meadow	21	0.204
" "	30	0.241

NOTE VI. (p. 141).

In connection with the loss by drainage of nitrogen in the form of nitrates, it may be mentioned that the water of many of the famous rivers contains large quantities of nitrates. Thus the water of the Seine has been found to contain fifteen parts of nitrates per million of water, and the Rhine eight parts per million. Some idea of what this

amounts to per annum may be obtained by the statement that "the Rhine discharges daily 220 tons of saltpetre into the ocean, the river Seine 270, and the Nile 1100 tons."—(Storer's Agric. Chem., vol. i. p. 318.)

NOTE VII. (p. 142).

EXAMPLES OF DECREASE OF NITROGEN IN ROTHAMSTED SOILS.

	Nitrogen in 1st 9 inches.
	Per cent.
Old pasture	0.250
Arable land in ordinary culture	0.140
Wheat unmanured, 38 years	0.105
Wheat and fallow unmanured, 31 years . .	0.096
Barley unmanured, 30 years	0.093
Turnips unmanured, 25 years	0.085

MANURING, PRODUCE OF WHEAT, AND ALTERATION IN THE COMPOSITION OF THE SOIL IN BROADBALK FIELD, ROTHAMSTED, FROM 1865 TO 1881.

Plot.	Manures per acre, annually applied, 16 years, 1865-81.	Average produce per acre.		Nitrogen per acre in 1st 9 inches of soil.		
		Dressed grain.	Total produce.	1865.	1881.	Gain or loss in 16 years.
		bush.	lb.	lb.	lb.	lb.
3	Unmanured	11 $\frac{1}{2}$	1715	2507	2404	-103
5a	Mixed mineral manure	12 $\frac{3}{4}$	1963	2574	2328	-246
10a	Ammonium salts, 400 lb.	17 $\frac{1}{2}$	2881	2548	2471	-77
11a	" " with superphosphate	23 $\frac{1}{4}$	3856	2693	2676	-17
7a	" " with mixed mineral manure	28	4993	2829	2908	+79
9a	Nitrate of soda, 550 lb., and mixed mineral manure	36	6949	2834	2883	+49
16a	Unmanured*	13 $\frac{1}{2}$	2194	2907	2557	-350
2	Farmyard manure, 14 tons	31 $\frac{1}{2}$	5356	4329	4502	+173

* During 1852-64 received annually ammonium salts, 800 lb., with mixed mineral manure, and yielded an average product of 30 $\frac{1}{2}$ bushels of grain and 46 $\frac{1}{2}$ cwt. of straw.

NOTE VIII. (p. 141).

AMOUNT OF DRAINAGE AND NITROGEN AS NITRATES IN
DRAINAGE-WATER FROM UNMANURED BARE SOIL, 20
AND 60 INCHES DEEP—AVERAGE OF THIRTEEN YEARS.

	Rain- fall.	Amount of drainage.		Nitrogen as nitrates.			
				Per million of water.		Per acre.	
		20-inch gauge.	60-inch gauge.	20-inch gauge.	60-inch gauge.	20-inch gauge.	60-inch gauge.
	Inches.	Inches.	Inches.			lb.	lb.
March	1.70	0.85	0.94	7.3	8.9	1.41	1.89
April	2.25	0.72	0.79	8.3	9.0	1.35	1.61
May	2.48	0.80	0.79	8.4	9.1	1.53	1.63
June	2.59	0.78	0.78	9.2	9.1	1.62	1.60
July	2.85	0.68	0.62	13.5	11.8	2.08	1.66
August	2.69	0.84	0.76	15.1	13.3	2.87	2.28
September . . .	2.70	0.97	0.82	17.7	13.4	3.86	2.50
October	3.12	1.86	1.68	13.8	11.9	5.83	4.53
November . . .	3.20	2.44	2.32	11.8	11.4	6.50	5.98
December . . .	2.34	1.88	1.88	9.5	10.6	4.06	4.51
January	2.13	1.79	1.93	7.4	8.9	2.99	3.88
February . . .	2.16	1.84	1.74	7.7	9.1	3.19	3.57
March-June . .	9.02	3.15	3.30	8.3	9.0	5.91	6.73
July-September	8.24	2.49	2.20	15.6	13.0	8.81	6.44
October-Feb. .	12.95	9.81	9.55	10.2	10.4	22.57	22.47
Whole year . .	30.21	15.45	15.05	10.7	10.5	37.29	35.64

CHAPTER IV.

NITRIFICATION.

THE most important compound of nitrogen for the plant is *nitric acid*. It is as nitrates that most plants absorb the nitrogen they require to build up their tissue. In nature the nitrogen, present in the soil as ammonia and different organic forms, is constantly being converted into nitric acid. This conversion of nitrogen into nitrates, known as *nitrification*, is a process of very great importance, and, as has been already pointed out in the Introductory Chapter, is effected through the agency of micro-organisms (ferments).¹ The process of nitrification, as well as the nature of the other changes taking place in the soil between the various compounds of nitrogen, are as yet but most imperfectly understood, but much light has been thrown on this most interesting department of agricultural research during the last few years; and it cannot be doubted that the increased attention which it is receiv-

¹ As the formation of nitrites is a stage in the process, the term *nitrification* includes the formation of nitrites as well as nitrates.

ing from different investigators, both on the Continent and in this country, will be fraught with most important results for practical agriculture.

Occurrence of Nitrates in the Soil.

The occurrence of nitre,¹ or potassium nitrate, in soils has been long known, although it is only within the last few years that we have obtained any precise knowledge with regard to the mode of its production. While its amount in most soils, especially in this country,² is very minute, there are certain parts of the world where nitrates are found in large quantities. The nitrate fields of Chili and Peru are the chief natural sources of nitrates, and they are referred to in the chapter on Nitrate of Soda. We have other parts of the world, however (in China and India), where soils rich in nitre occur, and which in the past have formed a source of the commercial article.³

Nitre Soils of India.

The most important of these nitre soils are those found in the North-west of India, in the province of Bengal. In these districts the soil is of a light porous texture, rich in lime, and situated at a considerable height above water-level. They are the sites of old

¹ Nitre seems to have been known as early as the thirteenth century.

² Lawes and Gilbert, for example, have shown that in the Rothamsted soils it only amounts to a few parts per million of soil.

³ See Appendix, Note I., p. 196.

villages, and the nitre is found in the form of an efflorescence on the surface of different parts of the soil. The occurrence of nitre under such conditions is due, partly to the natural richness of the soil in nitrogen, and partly to its artificial enrichment through receiving the nitrogenous excrements of the inhabitants of the villages and their cattle. The constant process of evaporation going on in such a warm climate has the effect of inducing an upward tendency of the soil-water, the result being a concentration of all the nitre the soil contains in its surface layer. This goes on until a regular incrustation is formed, and the soil is covered by a white deposit of nitre. Whenever this becomes apparent, the surface portion of the soil is scraped off by the *sorawallah*, or native manufacturer, and collected and treated for the purpose of recovering, in a pure state, the saltpetre.

Saltpetre Plantations.

The large demand for saltpetre, larger than could be supplied by these nitre soils, soon gave rise to the semi-artificial method of production, formerly so largely practised in Switzerland, France, Germany, Sweden, and in many other parts of the Continent, by means of the so-called "nitre beds," "nitreries," or "saltpetre plantations." Previous to the introduction of this method of manufacture, the demand for saltpetre for gunpowder had become so great, that every source of nitre was eagerly sought for. Thus, when it was

discovered that the earth from the floors of byres, stables, and farmyards were particularly rich in nitre, and when mixed with wood-ashes formed an important source of it, the right to remove these in France was vested in the Government under the Saltpetre Laws, which obtained till the French Revolution. This great scarcity soon led, however, to a careful investigation being made into the conditions under which potassium nitrate was formed in nitre soils.¹ These conditions, which included the presence of rich nitrogenous matter, warmth, free aeration of the soil, and a certain proportion of moisture, became, in the course of years, more and more thoroughly understood, and the result was the institution of numerous "saltpetre plantations." These generally consisted of heaps of mould, rich in nitrogen, mixed with decomposing animal matter, rubbish of various kinds, manurial substances, ashes, road-scrappings, and lime salts.² The heap was interlaid with brushwood, and was watered from time to time with liquid manure from stables, consisting chiefly of dilute urine. In forming the heap care was taken to keep the mass porous, so

¹ The artificial production of nitre seems to have been first effected by Glauber in the seventeenth century.

² The lime-rubbish from old buildings, especially those parts which have come in contact with the earth, or plastering from the walls of damp cellars, barns, stables, &c., have been found to be rich in nitrate of lime, and, as has been long well known, constitute by themselves a valuable manure. The formation of the nitrate of lime can be accounted for by the contact of the lime with nitrogenous matter of different kinds.

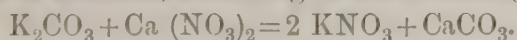
as to admit of the free access of air. The heap was further protected from the rain by covering it with a roof. In course of time considerable quantities of nitrates were developed, and the nitre was occasionally collected by scraping it from the surface, where it became concentrated just as in the nitre soils. In all cases, however, the heaps, when considered rich enough in nitre, were treated from time to time with water which, by subsequent evaporation, yielded the nitre in a more or less pure condition.¹

This mode of obtaining nitre is no longer practised to any extent, since it is now more conveniently obtained from the treatment of nitrate of soda with potassium chloride.

Cause of Nitrification.

We have adverted to these nitre plantations as showing how the conditions most favourable for the development of nitrification were recognised long before anything was known as to the true nature of the process. It was only in 1877 that the formation of nitrates in the soil was proved to be due to the action

¹ As much of the nitric acid in this solution was present as nitrate of lime, it was usually treated with a solution of potassium carbonate, the result being the precipitation of the lime as carbonate, pure salt-petre being left in solution, according to the following equation—



Under the French mode of manufacture, the process was considered to have developed satisfactorily when 1000 lb. of earth, at the expiration of two years, yielded 5 lb. of nitre.

of micro-organic life,¹ by the two French chemists, Schloesing and Müntz, who discovered the fact when carrying out experiments to see if the presence of humic matter was essential to the purification of sewage by soil. In these experiments sewage was made to filter slowly through a certain depth of soil (the time occupied in this filtration being eight days). It was found that nitrification of the sewage took place. By treating the soil with chloroform² it was found that it no longer possessed the power of inducing the nitrification of the sewage. When, however, a small portion of a nitrifying soil was added, the power was regained. From this it was naturally inferred that nitrification was effected by some kind of ferment. This conclusion was soon confirmed by subsequent experiments by Warington at Rothamsted, who showed that the power of nitrification could be communicated to media, which did not nitrify, by

¹ Pasteur had already in 1862 expressed the opinion that nitrification might probably be in some way connected with ferments. A. Müller (see 'Journal of Chemical Society,' 1879, p. 249) was the first to advance the opinion that nitrification was due to the action of a ferment. This conclusion he was led to by the observation that while the ammonia in sewage was converted into nitric acid, no change took place in solutions of ammonia or urine prepared in the laboratory.

² Bisulphide of carbon and phenol (carbolic acid) have also been experimented with in connection with their antiseptic action on nitrification. In these experiments the former had a similar effect to chloroform; the phenol, however, while hindering it did not entirely suspend it, due probably to the difficulty of bringing the phenol vapour into thorough contact with the soil-particles.

simply seeding them with a nitrifying substance, and that light was unfavourable to the process. Since then the question has formed the subject of a number of researches by Mr Warington at Rothamsted, as well as by Schloesing and Müntz, Munro, Dehérain, P. F. Frankland, Winogradsky, Gayon and Dupetit, Kellner, Plath, Pichard, Landolt, Leone, and others. From these researches we have obtained the following information with regard to the nature of the organisms concerned in this process, and the conditions most favourable for their development.

Ferments effecting Nitrification.

The importance of isolating and studying them microscopically was recognised at an early period in these researches. Messrs Schloesing and Müntz were the first to attempt this. They reported that they had successfully accomplished this, and described the organism as consisting of very small, round, or slightly elongated corpuseles, occurring either singly or two together. According, however, to the most recent researches of Warington, Winogradsky, and P. F. Frankland, nitrification is not effected by a *single* micro-organism, but by *two*, both of which have been successfully isolated and studied.¹ The first of these to be discovered and isolated was the *nitrous* organism, which effects the conversion of ammonia into nitrous

¹ Winogradsky has named the nitrous organism *nitrosomonas*, and the nitric organism *nitrobaeter*.

acid; the second, which has only been lately isolated by Warington and Winogradsky, effects the conversion of nitrous acid into nitric acid. Each of these ferments thus has its distinctive function to perform in this most important process, the nitric ferment being unable to act on ammonia, as the nitrous ferment is unable to convert nitrites into nitrates. Both ferments occur in enormous quantities in the soil, and seem to be influenced, so far as is at present known, by the same conditions. Their action will thus proceed together. Nearly all we know as yet on the subject of their nature is with regard to the nitrous ferment.

Appearance of Nitrous Organism.

Mr Warington¹ thus describes the appearance of the nitrous organism: "As found in suspension in a freshly nitrified solution, it consists largely of nearly spherical corpuscles, varying extremely in size. The largest of these corpuscles barely reaches a diameter of $\frac{1}{1000}$ th of a millimeter; and some are so minute as to be hardly discernible in photographs, although shown there with a surface one million times greater than their own. The larger ones are frequently not strictly circular. These forms are universally present in nitrifying cultures. The larger organisms are sometimes seen in the act of dividing."

¹ From a series of Lectures delivered by him in connection with Lawes Agricultural Trust, in the United States.

Nitric Organism.

So far as at present known, the nitric organism is very similar in appearance to the nitrous organism, so much so that it is difficult to distinguish the one from the other. As the same conditions influence their development, the process may be regarded as a whole.

Difficulty in isolating them.

A great difficulty has been experienced in the attempt to isolate these micro-organisms for the purpose of studying their nature. This arises from the fact that they refuse to grow on the ordinary solid cultivating media used by bacteriologists. Wino-gradsky, however, has recently succeeded in cultivating them in a *purely mineral* medium—viz., *silica-jelly*.¹

Nitrifying Organisms do not require Organic Matter.

The fact that they can develop in media destitute of organic matter, is one of very great interest and importance to Vegetable Physiology. It implies that they can derive their carbon from carbonic acid—a power which it was believed was possessed by green plants alone among living structures. For organisms destitute of chlorophyll, the source of their protoplasmic carbon, it has been hitherto commonly believed,

¹ This silica-jelly consists of dialysed silicic acid, ammonium sulphate, potassium phosphate, magnesium sulphate, calcium chloride, and magnesium carbonate.

must be *organic matter* of some sort. While it would appear that the nitrifying organisms can, when opportunity affords, feed upon organic matter, yet it has been proved beyond doubt that they can also freely develop in media entirely devoid of it, and are capable, under such circumstances, of deriving their carbon from a purely mineral source.¹ This fact, which is subversive of what was believed to be a fundamental law of Vegetable Physiology, is one of the most important of the many important and interesting facts which these nitrification researches have elicited.²

CONDITIONS FAVOURABLE FOR NITRIFICATION.

We may now proceed to discuss the conditions favourable for nitrification.

Presence of Food-constituents.

Among these conditions the first is the presence of certain food-constituents. To both animal and vegetable life alike a certain amount of mineral food is absolutely necessary. Among these phosphoric acid is one of the most important, and in the experiments on nitrification it has been found that the nitrifying organisms will not develop in any medium destitute

¹ This fact is all the more striking when we remember that this decomposition of carbonic acid is best effected in the dark, since light is prejudicial to nitrification.

² See Appendix, Note II., p. 196, and Note III., p. 197.

of it. That other mineral food-constituents are necessary is highly probable, although the influence of their absence on the development of the process has not been similarly studied. Probably potash, magnesia, and lime salts are necessary. In the cultivating solutions used in the experiments on the subject, the mineral food-constituents added consisted of lime, magnesia, and potash salts and phosphoric acid.¹

As we have seen above, the presence of organic matter is not necessary for the process. In this respect these organisms are differentiated from all other ferments hitherto discovered.

Presence of a Salifiable Base.

The presence of a sufficient quantity of a base in the soil with which the nitric acid may combine, when it is formed, is another necessary condition.² The process only goes on in a slightly alkaline solution. The substance which acts as this salifiable base is *lime*. The presence of a sufficient quantity of carbonate of lime in the soil will thus be seen to be of first-rate importance. This furnishes an explanation of one of the many benefits conferred by

¹ See Appendix, Note V., p. 198.

² This is shown by the fact that nitrification will only continue in a solution of carbonate of ammonia till one-half the ammonia is nitrified. It then stops. The base, with which the nitrous acid combines as it is formed, being at that stage entirely used up, nitrification is no longer possible. With regard to urine solutions the same is the case. Nitrification thus will only take place where there is a sufficiency of base.

lime on soils. The activity of nitrification in many soils may be hindered by the absence of a sufficiency of lime salts, and in such cases most striking results may follow the application of moderate dressings of chalk. The absence of the nitrifying organisms in certain soils, such as peaty and forest soils, may be thus accounted for. In such soils humic acids are present and the requisite alkalinity is thus wanting.

Only takes place in slightly Alkaline Solutions.

But while a certain slight amount of alkalinity is necessary, this must not exceed a certain strength, otherwise the process is retarded. This is the reason why strong urine solutions do not nitrify. The amount of carbonate of ammonia generated in them by putrefaction renders the development of nitrification impossible by rendering the alkalinity of the solution too great.¹ The practical importance of this fact is considerable, as it shows the importance of diluting urine very considerably before applying it as a manure. Similarly, when large quantities of lime, especially burnt lime, are applied to soils, the result will be to arrest the action of nitrification for the time. The presence of alkaline carbonates in the soil, unless in minute quantities, is apt, therefore, to seriously interfere with the process.²

¹ See Appendix, Note IV., p. 197.

² It would seem that an alkalinity much exceeding four parts of nitrogen per million is prejudicial to the process.

Action of Gypsum on Nitrification.

It has been found by Pichard that the action of certain mineral sulphates is extremely favourable to the process, and among these *gypsum*. Warington has carried out some experiments on the action of gypsum in promoting nitrification. The reason of its favourable action is probably because it neutralises the alkalinity of nitrifying solutions. It thus permits the process to go on in unfavourable conditions. Where, therefore, too great alkalinity exists for the maximum development of nitrification, the best specific will be found to be gypsum.¹ The practical value of gypsum as an adjunct to certain manurial substances, where nitrification is desired to be promoted as rapidly as possible, such as sewage and farmyard manure, will thus at once become apparent. So far as there is a proper degree of alkalinity maintained, the presence of large quantities of saline matter does not seem to interfere with the process.

Presence of Oxygen.

The nitrification bacteria belong, it would seem, to the aërobic ² class of ferment—*i.e.*, they cannot develop without a free supply of oxygen. Exclusion of the air

¹ According to Warington, solutions containing 50 per cent of urine become nitrifiable when sufficient gypsum is added. The gypsum neutralises the alkalinity of nitrifying solutions by converting the alkaline ammonium carbonate into neutral ammonium sulphate, the calcium carbonate being precipitated.

² See Chapter on Farmyard Manure.

is sufficient to kill them, and in those portions of the soil where access of air is not freely permitted, nitrification will be found to be correspondingly feeble. Thus it has been found in experiments with different portions of soils, that but little signs of nitrification occur in the lower soil layers. According to experiments by Schloesing on a moist soil, in atmospheres respectively containing no oxygen and varying quantities of it, the action of oxygen in promoting nitrification was strikingly demonstrated. In an atmosphere of pure nitrogen, entirely devoid of oxygen, the process no longer took place, but the nitrates already present in the soil were reduced and free nitrogen was evolved. In an atmosphere, on the other hand, containing 1.5 per cent of oxygen, a considerable amount of nitrification took place; while in the presence of 6 per cent, nitrification took place to double the extent. An addition of 10 to 15 per cent again doubled the quantity. When the amount of moisture added was increased, the effect of larger percentages of oxygen was found to be less marked. The reason of this is that the oxygen probably acts as dissolved oxygen; the addition of water meaning at the same time an addition of available oxygen. This condition exemplifies the value of tillage operations. The more thoroughly a soil is tilled the more thoroughly will the aeration of its particles take place, and consequently the more favourable will this necessary condition of nitrification be rendered. The benefits

conferred on clayey soils by tillage will in this respect be especially great.

Temperature.

Another of the conditions determining the rate at which nitrification takes place, and one which is most important, is *Temperature*. According to Schloesing and Müntz the temperature at which maximum development takes place is 37°C.^1 (99°F.), at which temperature it is ten times as active as at 14°C. (57°F.) Below 5°C. (40°F.) the action is extremely feeble. It is clearly appreciable at 12°C. (54°F.), and from there up to 37°C. (99°F.) it rapidly increases. From 37°C. (99°F.) to 55°C. (131°F.), at which temperature no nitrification takes place, its activity decreases; at 45°C. (113°F.) it is less active than at 15°C. (59°F.), and at 50°C. (122°F.) it is very slight. These results by Schloesing and Müntz have not been exactly confirmed by Warington. He has found that a considerable amount of nitrification goes on at a temperature between 3° and 4°C. (37° and 39°F.), while the highest temperature at which he has found it to take place is considerably lower than 55°C. (131°F.) Thus he was unable to start nitrification in a solution maintained at 40°C. (104°F.) It would thus seem that the nitrifying ferments are able to

¹ As practically illustrating this fact, a solution kept at 10°C. required ten days, while a solution kept at 30°C. required only eight days for nitrification.

develop at lower temperatures than most organisms and although nitrification entirely ceases during frost yet in a climate such as our own there must be considerable proportion of the winter during which nitrification is moderately active.

Presence of a sufficient quantity of Moisture.

The presence of moisture in a soil is another of the necessary conditions of nitrification. It has been shown that it is at once arrested, and indeed destroyed by desiccation. Other conditions being equal, and up to a certain extent, the more moisture a soil contains the more rapid is the process. Too much water, however, is unfavourable, as it is apt to exclude the free access of air, which, as we have just shown, is so necessary, as well as to lower the temperature. During a period of drought the rate at which nitrification takes place will, therefore, be apt to be seriously diminished.

Absence of strong Sunlight.

It has been found that the process goes on much more actively in darkness; indeed Warington has found in his experiments that nitrification could be arrested by simply exposing the vessel in which it was going on to the action of sunshine.

Nitrifying Organisms destroyed by Poisons.

It has already been pointed out that nitrification is arrested by the action of antiseptics, such as chloro-

form, bisulphide of carbon, and carbolic acid. Another substance which has been found to have an injurious action is ferrous sulphate or "copperas," a substance which is apt to be present in badly drained soils, or soils in which there is much actively putrefying organic matter. Maercker has found that in moor soils containing ferrous sulphate, no nitrates, or mere traces of nitrates, could be found. A substance such as gas-lime, unless submitted to the action of the atmosphere for some time, would also have a bad effect in checking nitrification, owing to the poisonous sulphur compounds it contains. Common salt, it would seem, also arrests the process; and this anti-septic property which salt exercises on nitrification throws a certain amount of light on the nature of its action when applied, as it is often done, along with artificial nitrogenous manures.

Denitrification.

In connection with the process of nitrification, it is of interest to notice that a process of an opposite nature may also take place in soils—viz., *denitrification*—a process which consists in reducing the nitrates to nitrites, nitrous oxide, or free nitrogen. That a reduction of nitrates takes place in the decomposition of sewage with the evolution of free nitrogen, was a fact first observed by the late Dr Angus Smith in 1867; and the reduction of nitrates to nitrites, and nitric and nitrous oxides in putrefactive changes has been

subsequently noticed by different experimenters, who have further observed that such reduction takes place in the case of putrefaction going on in the presence of large quantities of water or where there is much organic matter.

Denitrification also effected by Bacteria.

This change was supposed to be of a purely chemical nature, and it has only been recently discovered that it is effected, like nitrification, by means of bacteria. It has been surmised by some that the action of denitrification may be effected by the same organisms that effect nitrification, and that it depends on merely external conditions which process goes on. There is no reason, however, to suppose that this is so, and several of the denitrifying organisms have been identified.

Conditions favourable for Denitrification.

That it is a process that goes on to any extent in properly cultivated soils is not to be supposed. The conditions which favour denitrification are exactly the opposite of those which favour nitrification. It is only when oxygen is excluded, or, which practically means the same thing, when large quantities of organic matter are in active putrefaction, and the supply of oxygen is therefore deficient, that denitrification takes place. Schloesing, as we have already seen, found that in the case of a moist soil, kept in an atmosphere

devoid of oxygen, a reduction of its nitrates to free nitrogen took place.

Takes place in water-logged Soils.

The exclusion of oxygen from a soil may be effected by saturating the soil with water; and Warington has found in experiments carried out in an arable soil, by no means rich in organic matter, that complete reduction of nitrates may be effected in this way. It would thus seem that the process of denitrification will take place in water-logged soils, or in the putrefaction of sewage matter in the presence of large quantities of water. Whether this reduction will result in the production of nitrites, nitrous oxide, or free nitrogen, depends on different conditions. This process is one of great importance from an economic point of view, as it reveals to us a source of loss which may take place in the fermentation of manures. In the rotting of our farmyard manure it is possible that the denitrifying organisms may be more active than we have hitherto suspected, and that a considerable loss of nitrogen may in this way be effected.

Distribution of the Nitrifying Organisms in the Soil.

The nitrifying organisms are probably chiefly confined to the soil, and do not usually occur in rain or in the atmosphere. That, however, they are found in spots which we might be inclined to think extremely unlikely, is shown by some recent interesting researches

carried out by Müntz, who discovered that the bare surfaces of felspathic, calcareous, schistose, and other rocks at the summit of mountains in the Pyrenees, Alps, and Vosges, yielded large numbers of them, and that they occurred to a considerable depth in the cracks and fissures of the rocks. The nitrifying organisms are also found in river-water, in sewage, and well-waters.

Depth down at which they occur.

In Warington's earlier experiments, the conclusion he arrived at was that the occurrence of the nitrifying organisms was almost entirely limited to the superficial layers of the soil, and that they were seldom to be met with much below a depth of 18 inches. His subsequent experiments, however, considerably modified this conclusion, and showed that nitrification may take place to a depth of at least 6 feet.¹ But although it may take place at this depth, it probably, as a general rule, is limited to the surface-soil, as it is only there the conditions for obtaining circulation of air are sufficiently favourable. A great deal, of course, will depend on the nature of the soil—*i.e.*, as to its

¹ In sixty-nine trials no failure to produce nitrification by seeding with soil from a depth of 2 feet was experienced. Similarly in eleven trials only one failure took place with soil from a depth of 3 feet. With clay soil from a depth of 6 feet success took place to the extent of 50 per cent. No nitrification was obtained with clay from a depth of 8 feet. Entire failure was experienced with chalk subsoil. The process thus diminishes in activity the lower down we go.

texture. In a clayey subsoil the principal hindrance to nitrification will be the difficulty of obtaining sufficient aeration. In clay soils it is probable, therefore, that nearly all the nitrification goes on in the surface layer; in sandy soils it may take place to a greater depth.¹

Action of Plant-roots in promoting Nitrification.

In this connection the action of plant-roots in permitting a more abundant access of air to the lower layers of the soil, and thus promoting nitrification, is worth noticing. This has been observed in the case of different crops. Thus the action of nitrification has been found to be more marked in the lower layers of a soil on which a leguminous crop was growing than on that on which a gramineous. "The conditions which would favour nitrification in the subsoil are such as would enable air to penetrate it, as artificial drainage, a dry season, the growth of a luxuriant crop causing much evaporation of the water in the soil. Such conditions, by removing the water that fills the pores of the subsoil, will cause the air to penetrate more or less deeply and render nitrification possible. Subsoil nitrification will thus be most active in the drier periods of the year" (Warington).

Nature of Substances capable of Nitrification.

What kinds of nitrogenous substances are capable

¹ Koch has found that in soils he has examined few organisms were found at a depth below 3 feet.

of undergoing this process of nitrification are not yet well known. The question is, of course, one of great importance, as the rapidity with which a nitrogenous body nitrifies will be an important factor in determining its value as a manure. Unfortunately, on this subject we know, as yet, very little. We are well aware that the nitrogen present in the humic matter of the soil is readily nitrifiable. In the experiments on nitrification the nitrogenous bodies used have been chiefly ammonia salts, so that it is difficult to say whether, in the case of other nitrogenous substances, micro-organic life of a different sort has not also been active and has converted the nitrogen into ammonia, and thereby prepared the way for the process of nitrification.

That various manures, such as bones, horn, wool, and rape-cake are readily nitrifiable, has been shown by experiment. Laboratory experiments have also been carried out on such different nitrogenous substances as ethylamine, thiocyanates, gelatin, urea, asparagin, and albuminoids of milk. But in all these experiments, how far these bodies have been directly acted upon by the nitrifying organisms, or how far they have first undergone a preparatory change in which their nitrogen has been first converted into ammonia, is impossible to say. It is at least quite probable that all the organic forms of nitrogen have first to be converted into ammonia ere they are nitrified.

Rate at which Nitrification takes place.

A question which is practically of no little importance is the rate at which nitrification takes place. From what has been already said as to the nature of the conditions favourable for the process, it will be at once seen that this will depend on how far these conditions are present in the soil. In point of fact the rate at which nitrification takes place will vary very much in different soils. A greater difference, however, in the rate at which it takes place, will be found even in the same soils at different periods of the year. In this country, where the most favourable temperature for its development is seldom reached, it never goes on at the same rate as in tropical climates. One of the causes of the greater fertility of tropical soils is due, doubtless, to the very much longer duration of the period of nitrification, as well as to its greater intensity. As, however, temperature is not the only condition, and the presence of moisture is quite as necessary, it may be that its development is seriously retarded in many tropical climates by the extreme dryness of the soil during long periods.

Takes place chiefly during the Summer Months.

Although in this climate, as has already been pointed out, nitrification probably goes on during most of the winter months, owing to the fact that the temperature of our soils is only occasionally

below the minimum temperature at which the process takes place, yet there can be little doubt that the great bulk of the soil-nitrates are produced during a few months in summer. A fair conception of this amount is afforded by the interesting experiments on the composition of drainage-waters made at Rothamsted, which we shall have occasion to refer to immediately. It may be pointed out, however, that it is not always safe to take the amount of nitrates found in drainage-waters as an infallible indication of this rate, for this amount will depend to a certain extent on the amount of rainfall, and would be misleading in the case of a long period of drought. On the whole, however, it furnishes us with extremely useful data for the elucidation of this important problem.

Process goes on most quickly in Fallow Fields.

It has been shown in the Rothamsted experiments that the process goes on best in fields lying in bare fallow; and in this fact lies the explanation of one of the many reasons why the practice of leaving fields in bare fallow, so common in past times, and still practised in the case of clay soils in some parts of the country, was so beneficial to the land thus treated. But despite this fact, the practice of leaving soils in bare fallow can scarcely be justified from this point of view, as the loss of nitrates through the action of rain is very great in our moist climate.

Laboratory Experiments on Rate of Nitrification.

Several interesting experiments have been carried out with the object of affording data for estimating the rate at which the process may go on in our soils under certain conditions. An old experiment, carried out by Boussingault, illustrates, in a general way, how rapid the process is under favourable circumstances. A small portion of rich soil was placed on a slab protected by a glass roof, and was moistened from time to time with water. The amount of nitrate of potash formed under these circumstances was estimated from time to time during a period of two months. During the first month (August) the percentage was increased from .01 to .18 (equal to about 5 cwt. of nitrate of potash per acre). The increase during the second month (September) was very much less,—indeed only about a seventh of the amount.¹ The soil experimented with was an extremely rich garden soil, and all the conditions for nitrification were most favourable.

Of recent experiments on the rate of nitrification, the most striking, perhaps, are those by Schloesing. He mixed sulphate of ammonia with a quantity of soil fairly rich in organic matter, and containing 19 per cent of water. During the twelve days of active nitrification no less than 56 parts of nitrogen per million of soil were nitrified per day. Taking the soil to a depth of 9 inches, this would be equal to more

¹ See Appendix, Note VI., p. 198.

than 1 cwt. per acre—an amount of nitrogen equal to that contained in 6 cwt. of commercial nitrate of soda. These experiments are interesting as showing what is probably the maximum rate of nitrification under the most favourable circumstances, and where there is an abundant supply of easily nitrifiable nitrogen. That nitrification ever takes place in our soils to this extent is not to be for a moment supposed.

Warrington, in his Rothamsted experiments, has found that the greatest rate, working with ordinary arable soil (first 9 inches) from the Rothamsted farm, was .588 parts per million of air-dried soil per day—*i.e.*, 1.3 lb. per acre (equal to about 8 lb. of nitrate of soda). Similar soil, when supplied with ammonia salts, showed nearly double this quantity. Higher results were obtained by Lawes and Gilbert with rich Manitoba soils, the average rate being .7 parts per million per day.

The last of these interesting laboratory experiments on the rate of nitrification we shall refer to, are those by Dehérain. He experimented with soils containing different amounts of nitrogen and moisture. With a soil containing .16 per cent of nitrogen he obtained, during a period of 90 days, rates of nitrification varying from .71 to 1.09 per million parts of soil. The maximum quantity was formed when the soil contained 25 per cent of moisture. On a soil considerably richer—*viz.*, .261 per cent of nitrogen—a higher rate of nitrification took place—1.48 parts per million.

The highest rate obtained in these experiments showed, when calculated to pounds per acre, about $5\frac{1}{2}$, taking the soil to a depth of 9 inches. When the soil was alternately dried and moistened the process was most rapid.

Portion of Soil-nitrogen more easily Nitrifiable than the rest.

Lastly, it may be noticed that in the above-cited experiments, and others of a similar kind, the process goes on most rapidly at first, and steadily diminishes thereafter. This is due to the fact that there is generally a certain quantity of nitrogen in most soils in a more easily nitrifiable condition than the rest, so that when this becomes oxidised nitrification proceeds more slowly. It would further seem that the nitrogen of the subsoil is less easily nitrified than that of the surface-soil.

Rate of Nitrification deduced from Field Experiments.

While the above experiments throw much light on the question of the rate at which nitrification may go on under different circumstances, the results furnished by actual analyses of soils and their drainage-waters are of still more practical value; and the Rothamsted experiments fortunately furnish us with a number of these valuable results.

*Quantity of Nitrates formed in the soils of
Fallow Fields.*

These researches had to be carried out on soil taken from fields lying in bare fallow; for no true estimate of the amount of nitrates formed could have been obtained from *cropped* fields. In the first 27 inches of soil of six separate fields, nitrate-nitrogen was found to vary from 36.3 lb. to 59.9 lb. per acre. In four of these fields the largest proportion was found in the first 9 inches of soil; in the remaining two, in the second 9 inches; while the third 9 inches in two fields showed almost as large a proportion as the first 9 inches.¹

Position of Nitrates depends on Season.

The position of nitrates in the soil depends largely on the season; for, as has been already pointed out, their production is almost entirely limited to the surface-soil, and it is only by being washed down in rain that they find their way to the lower layers. A wet season, therefore, has the effect of increasing their percentage in the lower soil-layers.

Nitrates in Drainage-waters.

As there is a certain proportion of nitrates that finds its way even below the first 27 inches of soil, the above results do not show their total production.

¹ For full analytical results see Appendix, Note VII., p. 198.

To accurately estimate this amount we must ascertain the quantity escaping in drainage-water. Here, again, the Rothamsted experiments furnish us with valuable data. The amount found in drainage-waters of course naturally varies very much, and depends largely on the rainfall; but taking an average of twelve years, this has been found to amount to between 30 and 40 lb. per acre—an amount not so very far short of that found in the first 27 inches of the soil itself. This was from comparatively poor soil, it must be remembered, and a much larger quantity would undoubtedly be produced in the case of richer soils. Adding then the results together, we find that in soils like those at Rothamsted, when in bare fallow, between 80 and 90 lb. of nitrogen are converted into nitrates in some fourteen months' time—an amount equal to about 5 cwt. of nitrate of soda. It is a fact of no little practical significance that nearly one-half of this large quantity is found in the drainage-water.

Amount produced at Different Times of the Year.

Some indication of the rate at which nitrification takes place during the different months of the year is obtained from a study of the results of the analyses of drainage-waters which we have just referred to. This, however, it must be remembered, only furnishes us with a very approximate indication. The month showing the greatest amount of nitrates in the drainage-water must not necessarily be regarded as

that during which nitrification has been most active, for the amount chiefly depends on the rainfall. In illustration of this it will be found that the drainage-water during the autumn and early winter months contains most nitrates, not because nitrification is most active then, but because the rainfall is greatest, and a large proportion of the nitrates formed during the drier summer months is being only then washed from the soil. The amount of nitrates in drainage-waters steadily diminishes from autumn through the winter months, and is least in spring. The total amount of nitrates found in the drainage-water is, therefore, not a safe guide. What, however, does furnish us with a more reliable indication is the *percentage* of nitrates in the drainage-water. Regarding the results of the analyses of drainage-water (see Appendix) from this point of view, it will be seen that this is greatest during the month of September, and least during April.¹

Nitrification of Manures.

A subject which has not yet been specially referred to, but which is of great practical importance, is the nitrification of manurial substances. It is unfortunate

¹ We find the least amount in the month of April. In the water, from a 20- and 60-inch gauge respectively, the amounts were 1.35 lb. and 1.61 lb. per acre (rainfall 2.25 inches). From then on to November the amount steadily increases. In the latter month it reaches its maximum—viz., 6.50 lb. (20-inch gauge) and 5.98 lb. (60-inch gauge) per acre (rainfall 2.30 inches). See Appendix to Chapter III., Note VIII. p. 160.

that the amount of research hitherto devoted to this important question has been slight, and that the knowledge we possess is therefore very limited.

Ammonia Salts most easily Nitrifiable.

One fact, however, about which there can be little doubt, is that nitrogen in the form of ammonia salts is, of all compounds of nitrogen, the most easily nitrifiable. Indeed, as we have already indicated, it is highly probable that the conversion of the different forms of organic nitrogen into ammonia is an intermediate stage in the nitrification of these bodies. At any rate it seems to be invariably the case that when a mixture of nitrogen compounds, including ammonia salts, are allowed to nitrify, the nitrogen in the form of ammonia is the first to become nitrified.

Sulphate of Ammonia most easily Nitrifiable Manure.

It follows from this that sulphate of ammonia, the most common of ammoniacal manures, is one of the most speedily nitrified when applied to the soil. The rate at which the nitrification of this manure takes place naturally varies according to the quantity applied, and other circumstances, such as the nature of the soil and the weather, &c. That, under favourable circumstances, the conversion of ammonia into nitrates is very rapid, has been shown by a number of experiments. Dehérain has found that when sulphate of ammonia was mixed with soil at the rate of 2 cwt.

per acre, nitrification took place at the rate of $\frac{1}{100}$ th of its nitrogen per day.

Rate of Nitrification of other Manures.

Of other nitrogenous manures, guano, it would seem, comes next to sulphate of ammonia in the rate at which it becomes nitrified in the soil; while next to guano stand green manures, dried blood, meat-meal, &c. As we should expect, such a manure as shoddy is very slowly nitrified. The rate at which the nitrogen compounds in farmyard manure become nitrified, when incorporated with the soil, vary very much according to circumstances. It goes on probably at a greater rate than the ordinary nitrification of soil-nitrogen. It is a somewhat striking fact that the effect of adding nitrate of soda to the soil may be at first to check nitrification. That the addition of common salt, even in small quantities, has this result, is at any rate certain. The presence of salt to the extent of one-thousandth of the weight of the soil, has a prejudicial effect.

Soils best suited for Nitrification.

To recapitulate, then, nitrification is effected through the agency of micro-organisms, which are present to a greater or less extent in all soils. It requires for its favourable development air, warmth, moisture, absence of strong light, presence of a salifiable base—viz., carbonate of lime—the presence of certain mineral food-

constituents, such as phosphates, and a certain amount of alkalinity. It consequently takes place to the least extent in barren sandy soils. Soils rich, light, well ventilated, uniformly moist, warm, and chalky, are best suited for its development. Other things being equal, it develops better in a fine-grained soil than in a coarse-grained soil, because, in the case of the former, aeration and uniform moistening of the soil are best secured.

Absence of Nitrification in Forest-soils.

A point of considerable interest is the practical absence of the process in forest-soils. The absence, or occurrence in the most minute traces, of nitrates in forest-soils has been accounted for by the lowness of the normal temperature of such soils and their extreme dryness. This latter condition is accounted for by the enormous transpiration of water which takes place through the trees, especially in summer-time, which is such as to render the soil almost air-dry. Lastly, it may be accounted for by the want of mineral food ingredients.

Important Bearing of Nitrification on Agricultural Practice.

Before concluding this chapter, it may be well to draw attention to the important bearing which nitrification has on agricultural practice. The light which our present knowledge—imperfect as it is—of this

most interesting process throws on the theory of the rotation of crops is very striking, for it shows how the adoption of a skilful rotation may be made to prevent the loss of enormous quantities of the most valuable of all our soil-constituents,—the one on the presence of which fertility may be said most to depend—viz., nitrogen.

Desirable to have Soil covered with Vegetation.

The constant production of nitrates going on in the soil, the inability of the soil to retain them, and the consequent risk of their being removed in drainage, furnish a strong argument in favour of keeping our soils as constantly covered with vegetation as possible.

Permanent Pasture most Economical Condition of Soil.

From the point of view of conservation of soil-nitrates, permanent pasture may be said to be the most economical condition for the soil to be in. In such a case the nitrates are assimilated as they are formed, and, by being converted in the plant into organic nitrogen, they are at once removed from all risk of loss. A consideration, therefore, of the process of nitrification furnishes many arguments in favour of laying down land in permanent pasture—a practice which of late years has been increasingly followed in many parts of the country. As, however, it is not possible or desirable to carry out this practice beyond certain limits, the rotation which most nearly conforms to the con-

dition of keeping the soil covered with vegetation, and most approximates in this respect to permanent pasture, is most to be recommended.

Nitrification and Rotation of Crops.

The chief risk of loss of nitrates is in connection with a cereal crop such as wheat. Where turnips follow wheat, there is a period during which the soil is left uncovered, and during which most serious loss of nitrates is apt to ensue. The risk of loss is enhanced by the fact that the assimilation of nitrates by cereals ceases before the season of their maximum production in the soil. The soil is then left bare of vegetation during the autumn, which is the most critical period of all, and the result must be serious loss. In order to minimise this loss, the practice of growing catch-crops has been had recourse to. As, however, this practice will be dealt with elsewhere, nothing further need here be said.

APPENDIX TO CHAPTER IV.

NOTE I. (p. 162).

OLD THEORIES OF NITRIFICATION.

According to the old theories, nitrification was regarded as a simple case of the oxidation of nitrogen by the oxygen of the air, or by ozone. The union of nitrogen and oxygen, however, probably takes place only at very high temperatures, such as are formed during electric discharges. It is needless to point out that the union of nitrogen and oxygen in this way is not likely to occur in soils. According to other theories, nitrification was effected by means of the oxidation of ammonia. Ammonia, however, can only be oxidised to nitric acid by means of certain powerful oxidising agents, such as ozone or hydrogen peroxide. As, however, these substances are not found in the soil, it is much to be doubted whether nitric acid is ever formed in the soil in this way. It is possible, however, as held by some, that ferric oxide is capable of inducing this conversion. On the whole, however, most evidence points to the conclusion that all nitric acid produced in the soil is formed through the agency of micro-organic life.

NOTE II. (p. 170).

The important fact that nitrification can take place in solutions practically devoid of organic matter, was first shown by Dr J. H. M. Munro ('Chemical Society Journal,' August 1886, p. 561). It was further corroborated by Warington and P. F. Frankland. Winogradsky, however,

has carried out the most conclusive experiments on the subject. "He prepared vessels and solutions, carefully purified from organic matter, and these solutions he sowed with the nitrifying organism. Finding that under these conditions the nitrifying organism increased enormously and displayed its full vigour, he proceeded further to determine the amount of carbonaceous organic matter formed in solutions after the introduction of the organism. By making the nitrification intensive, he was able to obtain considerable quantities of carbon from the nitrified solutions by the process of wet combustion. In his third memoir he publishes figures which apparently show a close relation between the amount of nitrogen oxidised, and the amount of carbon assimilated; the ratio is about 35:1."—See Bulletin of U.S. Department of Agriculture, No. 8, containing Lectures on Rothamsted Experiments by R. Warrington, F.R.S., p. 50.

NOTE III. (p. 170).

The oxidising power of the micro-organisms of soil is not confined to the oxidation of ammonia or of organic matter. Müntz has shown that soil is capable of oxidising iodides to hypo-iodides and iodates, and bromides to hypo-bromides and bromates. This is a very important result, and seems to indicate that nitrification is part of a general oxidising action, and that we must not assume that nitrites or nitrates are produced because they are in themselves of advantage to the organism.

NOTE IV. (p. 172).

"When urine in different degrees of dilution was treated with soil, 1 gram of soil being added to 100 c.c. of diluted urine, nitrification commenced in the 1-per-cent solution in 11 days, in the 5-per-cent solution in 20 days, in the 10-per-cent solution in 62 days, in the 12-per-cent solution in 90 days. The alkalinity of the last-named solution when nitrification commenced was equal to 447 mgs. of

ammonia per litre. A solution with an alkalinity of 500 mgs. of ammonia per litre is apparently unnitrifiable."—American Department of Agriculture Bulletin, Warington's Lectures on Rothamsted Experiments, p. 51.

NOTE V. (p. 171).

Professor P. F. Frankland in his experiments used the following solutions:—

	grms.	} In 1000 c.c. of distilled water.
NH ₄ Cl . . . .	.5
H ₃ PO ₄ . . . .	.1
MgSO ₄ . . . .	.02
CaCl ₂ . . . .	.01
CaCO ₃	5.00	

NOTE VI. (p. 185).

Experiment by Boussingault on Rate of Nitrification.

1857.	Percentage of Nitrate of Potash.	= lb. per acre.
August 5 . . . .	.01	34
August 17 . . . .	.06	222
September 2 . . . .	.18	634
September 17 . . . .	.22	760
October 2 . . . .	.21	728

NOTE VII. (p. 188).

NITROGEN AS NITRATES IN ROTHAMSTED SOILS AFTER BARE FALLOW IN LB. PER ACRE.

Depth of Soil.	Alternate Wheat and Fallow.	Four-course rotation.			Claycroft Field.	Foster's Field.
		Super-phosphate only.	Mixed Manure.			
	1878.	1878.	1878.	1882.	1881.	1881.
1st 9 ins.	lb. 28.5	lb. 22.3	lb. 30.0	lb. 40.1	lb. 16.4	lb. 14.6
2d 9 ins.	5.2	14.0	18.8	14.3	26.5	24.6
3d 9 ins.	...	...	...	5.5	15.9	17.3
Total	33.7	36.3	48.8	59.9	58.8	56.5

CHAPTER V.

THE POSITION OF PHOSPHORIC ACID.

WE now come to consider the position of phosphoric acid in agriculture. The question is, however, very much simpler in its nature than that of nitrogen, and may be consequently discussed in a much shorter space.

Most soils, as we have already had occasion to point out, are better supplied with available ash-plant ingredients than available nitrogen compounds. The quantity of phosphoric acid absorbed by the plant is also less than that of nitrogen; and lastly, the different chemical compounds of phosphoric acid occurring in the soil are not nearly so numerous as those of nitrogen. Phosphoric acid, however, must be regarded as ranking next to nitrogen in its importance as a soil-constituent.

Occurrence of Phosphoric Acid in Nature.

That phosphoric acid is of universal occurrence may be assumed from the fact of the almost universal

occurrence of vegetable life on the earth's surface; for plants are unable to grow without it. While thus of practically universal occurrence, its amount in most soils is very trifling. As the only source of it in the soil is from the disintegration of the different rocks, a short description of its occurrence in the mineral kingdom may first be given.

Mineral Sources of Phosphoric Acid.

It was first discovered in the mineral kingdom towards the close of last century; but we have only of late years ascertained any exact knowledge of its percentage in the different rocks out of which soils are formed. This has been shown in many cases to be very trifling. It most abundantly occurs as *apatite*, a mineral consisting of calcium phosphate, with small quantities of calcium fluoride or calcium chloride. This *apatite*, or *phosphorite*, is found in certain parts of the world in large masses; but as a rule, it only occurs in small quantities in most rocks. It may be stated that the older rocks are, as a general rule, richer in it than those of more recent formation; and Daubeny has drawn attention to this fact as furnishing a useful guide in estimating the probable richness of a soil in phosphoric acid. The older, therefore, a rock is, the richer it is likely to be in phosphoric acid.

Apatite and Phosphorite.

Of *apatite* there are a variety of kinds, which differ

in their appearance as well as in their composition. It occurs chiefly in a crystalline form, and is found sometimes in regular crystals, but it also occurs in the amorphous form. In colour it may be white, yellow, brown, red, green, grey, or blue. Two classes of apatite are found. The first consists of calcium phosphate along with calcium fluoride; and in other kinds of apatite the calcium fluoride is replaced by calcium chloride. Phosphorite is another name for apatite, but is chiefly applied to impure amorphous apatite. The percentage of phosphate of lime in different kinds of apatite may be stated at from 70 to 90 per cent. It occurs in very large quantities in Canada, the Canadian apatite being very rich in phosphate of lime—80 to 90 per cent. In many parts of the world it forms portions of mountain-masses, and is quarried, crushed, and used for artificial manurial purposes. Further details of its occurrence and chemical composition will be found in the Appendix.¹

Coprolites.

In many parts of the world round nodules, largely consisting of phosphate of lime, have been found, to which the name “coprolites” has been given, on the assumption that they consisted of fossilised animal excrements. These coprolites, or osteolites as they have also been called, vary in the percentage of phosphate

¹ See Appendix, Note I., p. 210.

of lime they contain. Sometimes this amounts to 80 per cent, but as a rule it is very much less. They also in the past have formed an important source of manure, and will be referred to subsequently.

Guano.

We have, lastly, phosphoric acid occurring in large quantities in guano-deposits, chiefly found on the west coast of South America. These deposits, which have been of enormous importance as a source of artificial manure, are of animal origin, and will be discussed at considerable length in a chapter specially devoted to the subject; so that we need do no more than mention them here.

Phosphoric acid is also found in the form of phosphate of lime in certain rocks as "layers" and "pockets."

Universal Occurrence in Common Rocks.

But while it is thus found in considerable quantities in various parts of the world, and while no anxiety need thus be felt as to its abundance for artificial manurial purposes, its occurrence in the common rocks, which, as we have already pointed out, is practically universal, is in many cases very minute.

Fownes first identified it in the felspathic rocks in 1844; and since then its percentage in granite, lava, trachyte, basalt, porphyry, dolomite, gneiss, syenite, dolerite, diorite, and a number of other rocks, has

been determined by numerous investigators. For analyses of these rocks the reader is referred to the Appendix.¹

Occurrence in the Soil.

That no soil is actually without phosphoric acid is highly probable, but in many soils it is present in the merest traces, and even in fertile soils it is rarely present in quantities over two-tenths of a per cent; while half that amount may be taken as an average for most fairly fertile soils. This would be about 3500 lb. per acre, calculating the soil to a depth of 9 inches. In exceptional cases it has been found to the extent of .3 per cent; and in the famous Russian *black earth* it has been found to amount to .6 per cent.² Like nitrogen, it is found in greatest amount in the surface portion of the soil, but its amount at different depths does not vary to the same extent as we have found to be the case with nitrogen.

*Condition in which Phosphoric Acid is present
in the Soil.*

Unlike nitrogen, phosphoric acid occurs in the soil almost entirely in an *insoluble* form; and when applied to the soil in a soluble form, is speedily converted into an insoluble condition. Its most com-

¹ See Appendix, Note II., p. 211.

² These results, as indeed all soil percentages, are calculated on the soil in a dry condition.

monly occurring forms are as phosphates of lime, iron, and alumina. These facts are of importance to remember, as they explain why phosphoric acid is not found in drainage-water in any quantity. It also shows how little the risk of loss from drainage is in the application of artificial phosphatic manure to the soil.

Occurrence in Plants.

The percentage of phosphoric acid in plants, like other ash-constituents, is subject to considerable variation, and depends on a variety of conditions, such as the state of the plant's development, nature of soil, climate, season, treatment with manures, &c. All these conditions have a certain influence. The different parts of the plant have been found to contain it in different quantities. The tendency of phosphoric acid is to travel up to the higher portions of the plant with the progress of growth, and to finally accumulate in the seed. As illustrating this, it may be mentioned that the inner portion of the stalk of a ripe oat-plant has been found to contain only a seventeenth of the amount of phosphoric acid found in the same portion of the stalk of a young oat-plant. Similarly it may be mentioned that, while the ash of the grain of rye and wheat contains nearly half their weight of phosphoric acid, the percentage present in the ash of other parts of the plant amounts only to from 5 to 16 per cent. The percentage of phosphorus is greater in young plants than in mature plants; it

is greater also in quickly developed plants than in slowly developed plants.

In the plant, phosphorus is present chiefly in the albuminoids; and its absorption from the soil takes place in greatest quantity during the period of maximum growth. In beans and peas an oil containing phosphorus has been found.

Occurrence in Animals.

That phosphorus in different forms exists in animal tissue is well known. It is found both in the brain and in the nerves, as well as in nearly all the fluids of the animal body. It is, however, in the bones that it is most abundant, the mineral portion of which is almost entirely made of phosphate of lime,—a fact which renders bones such a valuable artificial manure. Altogether, phosphoric acid occurs in the animal body to the extent of 2.3 per cent. There is a point which we shall have occasion to draw the student's attention to further on in discussing the nature of farmyard manure—and that is, that the urine of the common farm animals is practically devoid of phosphoric acid.

Sources of Loss of Phosphoric Acid in Agriculture.

As we have already done in the case of nitrogen, we may now attempt to form some conception of the sources of loss and gain of phosphoric acid in the soil. The sources of loss may be divided into natural and

artificial. Of natural sources of loss we have only one, and that is loss by drainage.

Loss of Phosphoric Acid by Drainage.

We have already seen that the condition in which phosphoric acid is present in the soil is as insoluble phosphate. In drainage-water it occurs in mere traces. Minute though the amount seems when stated as percentage, and small as it appears beside the loss (from the same source) of nitrogen, it is yet, if considered for large areas, sufficiently striking. Thus it has been estimated that in the river Elbe there is carried off by drainage from the fields of Bohemia $2\frac{3}{4}$ million pounds (1200 tons) of phosphoric acid annually. This, it is true, is a very trifling amount compared with the annual loss of nitrogen from an equal area; but then it must be remembered, on the other hand, the sources of gain to the soil of this ingredient are not so numerous as are those of nitrogen, the only sources of phosphoric acid being in the manure applied to the soil, and that coming from the gradual disintegration of phosphatic minerals.

Artificial Sources of Loss.

The other sources of loss may be classed under the term artificial, and are connected with agricultural practice. Just as we have seen that in the case of nitrogen enormous quantities of that substance are constantly being removed from the soil in those crops

which are consumed off the farm, so, too, enormous quantities of phosphoric acid are being removed in the same way. As illustrating this fact, it may be mentioned that Professor Grandeau has recently estimated that in the entire crops grown in France in one year there are about 298,200 tons of phosphoric acid; while the amount returned in the dung of farm animals is only 157,200, or only about one-half of what is removed in the crops, leaving a deficit of 147,000 tons to be made good by the addition of artificial phosphatic manures, if the fertility of the soil is to be maintained. The same authority has calculated that in the bones of the entire farm animals in France there is no less a quantity than 76,820 tons of phosphoric acid.

As an example of how, in many cases, the amount of phosphoric acid removed from the farm is very often much greater than that restored, a case quoted by Crusius may be cited. This was a farm of 670 acres (Saxon) which had received only farmyard manure, and from which, during sixteen years, 985.67 cwt. of phosphoric acid had been sold off in the crops; while only 408.33 cwt. had been restored in the manure, leaving a loss of 577.34 cwt.

Phosphoric Acid removed in Milk.

A further source of loss is the phosphoric acid removed in milk. In the total annual yield of milk from one cow there may be from 11 to 12 lb. of phosphoric acid.

Loss in Treatment of Farmyard Manure.

The risks of loss of phosphoric acid in the treatment of farmyard manure are not so great as in the case of nitrogen. There is, however, a considerable risk, through want of proper precautions, of the soluble phosphates being washed away by rain.

Loss in Sewage.

The loss of phosphoric acid incurred by the present method of sewage disposal is not so large as the loss of nitrogen, inasmuch as the quantity of phosphoric acid contained in human excreta is very much less. Roughly speaking, it may be said to amount to a little less than one-third of the nitrogen lost in this way.

Sources of Artificial Gain of Phosphoric Acid.

To balance these losses, we have a practically unlimited supply of mineral phosphates for application as artificial manure, as well as large quantities of other manures, many of them already mentioned in connection with nitrogen, such as bones and guanos of all kinds. Quite recently, also, a large source of phosphoric acid has been opened up in the basic slag, a rich phosphatic bye-product obtained in considerable quantity in steel-works from the basic process of steel manufacture. We have also large quantities of phosphoric acid in the imported feeding-stuffs, for statistics regarding which we would refer our readers

to a previous chapter. The question of the actual amount contained in these sources is not of the same interest as in the case of nitrogen, and need not therefore detain us. We have sufficiently indicated the importance of phosphoric acid in agriculture by the statements above given. All further consideration of phosphoric acid must therefore be deferred to future chapters.

APPENDIX TO CHAPTER V.

NOTE I. (p. 201).

COMPOSITION OF APATITE (Voelcker).

(Kragerøe, Norway.)

Lime	52.16
Phosphoric acid	41.25
Chlorine	4.10
Fluorine	1.23
Oxide of iron	0.29
Alumina	0.38
Potash and soda	0.17
Water	0.42
	<hr/>
	100.00

Apatite is found in considerable quantities in America, Germany, France, Spain, Hungary, Norway, and Great Britain. According to Rose, apatite is made up of three molecules of tribasic calcium phosphate ($\text{Ca}(\text{PO}_4)_2$), combined with one molecule of calcium fluoride (Ca F_2) or one molecule of calcium chloride (CaCl_2) respectively.

The composition of the pure mineral should be—

<i>Chlorapatite.</i>					Per cent.
Calcium phosphate . . . . .	.	.	.	.	89.38
Calcium chloride . . . . .	.	.	.	.	10.62
<i>Fluorapatite.</i>					
Calcium phosphate . . . . .	.	.	.	.	92.31
Calcium fluoride . . . . .	.	.	.	.	7.69

NOTE II. (p. 203).

The following is a list of the commoner rocks in which the percentage of phosphoric acid has been determined. The results are taken from analyses by Nesbit, Schramm, Bergemann, Rose, Dehérain, Handtke, Petersen, Nessler, Muth, Fleischmann, Storer, and others:—

	Per cent.			
Felspar . . .	1.7			
Granite . . .	0.09	0.25	0.58	0.68
Lava . . .	1.21	1.8		
Trachyte . . .	0.30	0.66		
Basalt . . .	0.50	1.11		
Porphyry . . .	0.26			
Marl . . .	1.45	2.31	3.8	
Calcareous stones . . .	0.064	0.176		
Dolomite . . .	1.24			
Lias chalk . . .	1.39			
Gneiss . . .	0.18	0.78	1.51	
Syenite . . .	0.10			
Dolerite . . .	0.3	1.1	1.2	
Diorite . . .	0.5	0.69		

CHAPTER VI.

THE POSITION OF POTASH IN AGRICULTURE.

WE may, lastly, consider the position of *potash* in agriculture, the only ash ingredient of the plant, in addition to phosphoric acid, which it is as a rule necessary to add as a manure.

Potash of less Importance than Phosphoric Acid.

It is of far less importance than phosphoric acid, from the fact of its much more abundant occurrence in the soil, as well as from the fact that under the ordinary conditions of agriculture, although removed from the soil in considerable quantities by crops, it finds its way back again in the farmyard manure; for it has not the same tendency to accumulate in large quantities in the grain or seed as we have seen to be the case with phosphoric acid. On this account straw contains a much greater proportion of potash than phosphoric acid, and hence farmyard manure may be regarded as fairly rich in potash.

Occurrence of Potash.

Of all sources of potash the ocean must be regarded as the chief. Millions and millions of tons are present in a state of solution in the salt water of the ocean.¹ Like phosphoric acid, its occurrence in the rocks forming the earth's crust may be said to be practically universal. Many of the commonly occurring rocks and minerals are extremely rich in it, and by their disintegration furnish large quantities to the soil. Some of these rocks contain it in such abundance that they have been tried as potash manures; and were other more valuable sources less available than they actually are, such a practice might well be recommended. A volcanic rock known as *palagonite*, and that most commonly occurring of all potash minerals—viz., felspar—have both been experimented with in this way with considerable success.

Felspar and other Potash Minerals.

That felspar should prove, when finally ground, a valuable source of potash, is not to be wondered at when we remember that some varieties of it contain over 16 per cent. It has been calculated that a single cubic foot of this mineral is sufficient to supply an oak-wood, covering a surface of 26,910 square feet,

¹ According to Boguslawski and Dittmar, the total amount of potash calculated as sulphate of potash in salt water equals 1141×10^{12} tons.

with potash for a period of no less than five years.¹ Some idea of the enormous *potential* fertility of a soil containing felspar, so far as potash is concerned, may be obtained from this statement. It must be remembered, however, that it is only the orthoclase or potash felspars which contain large quantities of potash—other felspathic rocks, such as oligoclase and labradorite, being comparatively poor in it. Another commonly occurring mineral which is rich in potash is mica, which has been found to contain from 5 to 13 per cent. From this it follows that rocks which have large amounts of these minerals in their composition—such as granite, for example, which often contains 5 or 6 per cent of potash—form by their disintegration soils rich in this ingredient.

Stassfurt Salts.

But in addition to the sources of potash already mentioned, it exists in other forms in the earth's surface. Till within recent years it was obtained for commercial purposes from the ashes of plants, which, as we shall immediately see, are extremely rich in this ingredient; from salt water—this source giving rise to the so-called "salt gardens" on the coast of France; and from nitre soils in different parts of India, referred to already at considerable length. Large mineral deposits, however, have been recently discovered in the neighbourhood of Stassfurt

¹ See Storer's 'Agricultural Chemistry,' vol. ii. p. 291.

in Germany, and have since their discovery supplied all the potash required for manurial and other purposes. In these deposits (similar ones have also been found at Kalusz in the Carpathian Mountains) there are no less than five different minerals which contain potash. The form in which it is present is as sulphate or chloride, so that it is readily available for plants, and is of altogether very much greater value than the form in which it occurs in the minerals already mentioned—viz., as an insoluble silicate. Of the Stassfurt potash salts, the best known as a manure is *kainit*, which contains about 32 per cent of sulphate of potash. A list of the other potash minerals, with the particulars of their composition and the percentage of potash they contain, will be found in the Appendix.¹

Occurrence of Saltpetre.

We have already had occasion, in Chapter IV., when discussing the question of nitrification, to refer to the occurrence of nitrate of potash in certain soils in India, which have formed a large source of saltpetre used in commerce in the past.

Occurrence of Potash in the Soil.

From what has been said regarding the richness in potash of certain commonly occurring minerals, such as felspar, it is only natural to infer that most soils

¹ See Appendix, Note I., p. 220.

must contain large quantities of this substance; and this is so. The wonder is that potash, when applied as an artificial manure, should have such a marked effect in increasing the fertility of the soil, as is often the case. We must remember, however, that although a soil may contain large quantities of potash, there may be a very small percentage of the whole in an available form for the plant's needs.

Potash chiefly in insoluble Condition in Soils.

Potash occurs almost entirely in soils in a very insoluble form—viz., combined with silica as a silicate of potash. It is only by the slow disintegration of potash rocks that the potash they contain is set free for plant uses. When it is applied as an artificial manure, on the other hand, it is in a soluble form. In most soils the amount soluble in water probably lies between .001 and .009 per cent; that soluble in dilute acid solutions from .1 to .5 per cent; and that insoluble from .2 to 3.5 per cent of the soil. It is highly probable that a certain quantity of potash in the soil may exist in combination with humic and ulmic acids, forming insoluble potassium humates and ulmates.

Potash in Plants.

Of all the ash ingredients of plants, potash is the most abundant, as it forms on an average about 50 per cent of the total ash of plants—about 90 per cent of the alkalies. The ash of plants, indeed, was for long

the chief source of potash. Certain plants remove very large quantities from the soil. Of these roots, potatoes, the vine, the tobacco-plant, and hops may be mentioned as examples. It is present in large quantities in the grain of cereals, although, as we have already pointed out, not to the same proportional extent as phosphoric acid. It is found in the plant's extremities, such as twigs and new leaves, in greatest abundance.¹

Potash in the Animal Tissue.

It is also found in all parts of the animal body. Especially rich in potash salts are the blood corpuscles, which contain about ten times the amount contained in the serum. It is found in especial abundance in the fleece of sheep, which may contain more potash than that in the whole body of the sheep. Animal urine also contains potash in considerable quantities.

Sources of Loss of Potash.

The capacity of the soil to retain soluble potash compounds, while not equal to its capacity for retaining phosphoric acid, is yet very much in excess of its capacity for retaining nitrates. The result is, that potash is only found in comparatively minute traces in drainage water.² Taking the same example as we

¹ See Appendix, Note II., p. 220.

² According to Way, different samples of drainage waters were found only to contain from .00003 to .00031 per cent.

already cited in illustration of the loss of phosphoric acid, we find that the amount carried away in the course of a year in the waters of the Elbe from Bohemia is 97,000,000 lb. (43,300 tons).

Potash removed in Crops.

The amount of potash removed by the different crops from the soil will be considered in a subsequent chapter. We need only say here that the class of crops which remove the largest quantity are the root crops, especially mangels. The loss is least in the case of the cereals. The amount of potash contained in the straw of cereals is about three times the amount of that removed in the grain.

Potash removed in Milk.

Lastly, we may refer to the potash removed in milk, which, on an average, may be taken at 10 lb. per annum for each cow.

Potash Manures.

Of potash manures the chief are the sulphate and the chloride, or, as it is commercially known, the "muriate." The chief source of potash manures are the Stassfurt deposits already referred to. Wood-ashes have also been used in large quantities in the past (chiefly as a potash manure), and in some parts

of the world are still used. A considerable source of artificial potassic manures is the refuse manufacture of sugar-beet, such a large industry in Germany. Potash occurs as a constituent of certain other manures, more valuable for nitrogen and phosphoric acid, such as guano and dried blood.

APPENDIX TO CHAPTER VI.

NOTE I. (p. 215).

AMOUNT OF POTASH IN DIFFERENT MINERALS.

Felspars—		Percentage of potash.				
(a) Orthoclase . . .	{	9.11	10.28	11.07	12.12	12.47
		13.49	14.35	15.21	16.7	
(b) Oligoclase . . .		0.50				
(c) Labradorite . . .		0.33				
Mica	{	5.61	6.20	7.23	8.26	8.95
		9.00	10.25	12.40	13.15	
Amphibole		0.25	2.96			
Pyroxene		0.34	2.48			
Leucite		13.60	18.61			
Zeolites		0.30	9.35	0.98	4.93	

Stassfurt potash salts—		Per cent.
(a) Polyhallite, <i>potassium sulphate</i>		28
(b) Karnallite ($\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$), <i>potassium chloride</i>	24 to 27	
(c) Sylvin, pure <i>potassium chloride</i> .		
(d) Kainit ($\text{K}_2\text{SO}_4 \cdot \text{MgSO}_4 \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$), <i>potassium sulphate</i>		32
(e) Schoenite ($\text{K}_2\text{SO}_4 \cdot \text{MgSO}_4 \cdot 6\text{H}_2\text{O}$), pure <i>potassium magnesium sulphate</i> .		

NOTE II. (p. 217).

The quantity of potash obtainable from various plants in the manufacture of potashes on a large scale is illustrated by the following statements. 1000 lb. of the following vegetative products yield the following quantities of potashes :—

	lb.
Old spruce-wood	$\frac{1}{2}$
Old poplar-wood	$\frac{3}{4}$
Old oak-wood	$1\frac{1}{2}$
Corn-stalks	$17\frac{1}{2}$
Bean-stalks	20
Grape-vine twigs	40

(Storer, 'Agricultural Chemistry,' vol. ii. p. 108.)

PART III.

M A N U R E S

CHAPTER VII.

FARMYARD MANURE

FARMYARD MANURE is the oldest, and is still undoubtedly the most popular, of all manures. It has stood the test of long experience, and has proved its position as one of the most important of all our fertilisers. It is highly desirable, therefore, to make a somewhat detailed examination of its composition, and to see on what the variation in this depends; and, finally, to examine into the mode of its action as a manure.

That it should prove a valuable manure is scarcely to be wondered at, as it is originally formed from vegetable substance, and as it therefore contains all the elements present in the plant itself.

Its composition is very variable, and probably no two samples would yield exactly similar analyses. In this fact lies one of the chief difficulties of the treatment of the subject, and all statements

made in the following pages as to its chemical composition must be taken as *only approximate*.

We may divide its constituents into three classes.

1. That portion due to *solid excreta*.
2. The liquid portion, largely made up of dilute *urine*.
3. The *straw*, or other material, which is used as litter.

The composition of the manure will vary according to the proportion in which these three substances are present, as well as according to the composition of the substances themselves. It will consequently tend to a clearer apprehension of the subject if we first examine briefly the chemical composition of the solid excreta and urine of the farm animals.

1. *Solid Excreta*.

The manurial value of the solid excreta of animals—*i.e.*, the proportion they contain of *nitrogen*, *phosphoric acid*, and *potash*—depends on a variety of conditions.

The solid excreta of horses, sheep, cows, and pigs, are well known to possess different properties, as well as to vary in their composition.

What, however, has a still greater influence is the nature of the food. This is owing to the fact that the solid excreta are made up of undigested food. We can scarcely expect the same quality of solid excreta from an animal fed on poor diet as from an animal fed on very much richer diet. Again, the

percentage of the food voided in the solid excreta varies in the case of different animals.¹

Another consideration which enters into the question is the age, as well as the treatment, of the animal. A young animal, during the period of its growth, absorbs from its food into its system a larger quantity of the three fertilising substances, nitrogen, phosphoric acid, and potash, than is the case with an adult animal whose weight is neither increasing nor diminishing. A working horse, similarly, will return more of the nitrogen, phosphates, and potash in its dung than one not at work and which is permitted to gain in weight. The nature of the composition of the solid excreta, therefore, will depend on the nature of the *food, age, breed, condition, and treatment* of the animal.

Let us now investigate shortly the influence of the above considerations. The solid excrements of the common farm animals are generally distinguished from one another according to the rate at which they decompose or ferment on keeping. Thus horse-dung is generally known as a "hot" dung; while cow-dung, on the other hand, is known as "cool." Why this should be so is not absolutely clear. Probably it is owing to the fact that the former contains less water, as well as to the fact (and this probably has more to do with it) that it contains a larger percentage of fertilising matter, especially nitrogen, thus affording conditions

¹ See Appendix, Note I., p. 279.

more favourable for rapid fermentation than in the case of the more moist and less rich cow-dung.

The composition of the solid excreta of various animals, as we have just said, varies with the nature of their food; so that it is impossible to take any analyses as absolutely representing its composition. It may be interesting, however, to compare the analyses of samples of horse-dung with those of some other of the commoner farm animals, with a view to obtaining an *approximate* idea of this difference.

Stoeckhardt has found that in 1000 lb. of the fresh solid excreta of the animals below mentioned, there were the following amounts of *nitrogen*, *phosphoric acid*, and *alkalies*:—

	WATER.		NITRO-GEN.		PHOS-PHORIC ACID.		AL-KALIES.	
				Re-duced to		Re-duced to		Re-duced to
	lb.	per cent.	lb.	per cent.	lb.	per cent.	lb.	per cent.
Horses (winter food) . .	760	76	5	.50	3½	.35	3	.30
Cows (winter food) . .	840	84	3	.30	2½	.25	1	.10
Swine (winter food) . .	800	80	6	.60	4½	.45	5	.50
Sheep (2 lb. hay per diem) .	580	58	7½	.75	6	.6	3	.30

From the above table it will be seen that the sheep's dung contains the least percentage of *water*, and is richer in *nitrogen* and *phosphoric acid* than any of the other three. The percentage of alkalies, of which the most important is potash, is, however, not so large.

This may be accounted for by the interesting and well-known fact that a large percentage of potash is to be found in the wool of sheep.¹

The solid excrement of the sheep is, therefore, weight for weight, the most valuable as a manure, as it contains more nitrogen and phosphates than the others, and at the same time is much drier.

If, however, we compare the composition of the solid excreta in a dry state, we shall find that the following are the results (basing our calculation on Stoeckhardt's analyses):—

	Nitrogen, per cent.	Phosphoric acid, per cent.	Alkalies, per cent.
Horse. . . .	2.08	1.45	1.25
Cow	1.87	1.56	0.62
Pig	3.00	2.25	2.50
Sheep. . . .	1.78	1.42	0.71

It will be seen from the above that the dry substance of the solid excreta of the pig is richest in fertilising substances. Too much stress, however, as has already been pointed out, must not be put on any single analysis, as so much depends on various conditions, especially the food.² The most reliable method of studying this question, therefore, is to study it in its relation to the food consumed. Wolff has calculated from numerous investigations that,

¹ "The large amount of potash in unwashed wool is very remarkable: a fleece must sometimes contain more potash than the whole body of the shorn sheep."—Warington's 'Chemistry of the Farm,' p. 78.

² See Appendix, Note II., p. 279.

with regard to the amount of solid excreta produced by the food, the following percentage of *organic matter*, *nitrogen*, and *mineral substances*, originally present in the dry matter of the food, is voided in the dung:—

	Cow.	Ox.	Sheep.	Horse.	Average.
Organic matter . . .	39.5	42.5	44.0	44.1	42.5
Nitrogen . . .	47.5	33.9	46.7	32.4	40.1
Mineral substances	53.9	64.6	57.9	62.5	59.7

There is one fact to be borne in mind in estimating the manurial value of the dung of different animals—viz., that the quantity of dung voided by one animal is much greater than that voided by another. Thus the amount voided by the cow, for example, is much greater than that voided by the horse; so that, in this way, the inferior quality of the former is, to some extent, compensated for by its greater quantity.

2. *Urine.*

The solid excreta possess, however, very much less manurial value than the urine. The former, as already stated, are undigested food-substances: any fertilising matters which they contain are such as have failed to be digested or absorbed into the animal system. The urine, on the other hand, contains those fertilising substances which have been digested.

The amount of nitrogen and mineral matter, however, in the urine, does not represent necessarily the total amount of these substances. Thus, in the case of a growing or fattening animal, there is always a

certain amount of these substances being absorbed to build up the animal tissue and put on flesh.

In this respect it will be seen that the composition of urine will vary in the same way as that of the dung. In the case of the urine, however, there is a compensating influence to be taken into account. Urine is a waste product, and there is more waste in a young than in an adult animal.

Another very important condition which determines the composition of urine is the nature of the food, especially the quantity of water drunk. This, of course, is obvious: the more water drunk, the poorer must the composition of the urine be. But here again, as in the case of the dung, this is largely compensated for by the total quantity voided—the more dilute the urine, the larger will its quantity be; so that the inferior quality is in this way made up for by its increased quantity.

Keeping in mind, then, the fact we have just stated—viz., that the composition of urine will vary according to different conditions—we may obtain an approximate idea of what its composition is from the following results of analyses by Stoeckhardt. In 1000 parts the following quantities of *water*, *nitrogen*, *phosphoric acid*, and *alkalies* were found to be present.

From the following table it will be seen that the urine of swine (containing 97 per cent of water) is much poorer in nitrogen and alkalies than is the case with

the urine of the sheep, horse, or cow.¹ While this is the case, the amount of phosphoric acid it contains is greater than that contained in the sheep's urine.

	WATER.		NITROGEN.		PHOSPHORIC ACID.		ALKALIES.	
	Per 1000 parts.	Per cent.	Per 1000 parts.	Per cent.	Per 1000 parts.	Per cent.	Per 1000 parts.	Per cent.
Sheep (2 lb. hay } per diem)	865	86.5	14	1.4	.5	.050	20	2.0
Swine (winter food)	975	97.5	3	.3	1.25	.125	2	.2
Horses (hay and } oats)	890	89.0	12	1.2	...	...	15	1.5
Cows (hay and } potatoes)	920	92.0	8	.8	...	...	14	1.4

Phosphoric acid is present in the urine of the farm animals in the most minute traces : practically, it may be considered to be wanting in the urine of the horse and the cow, and is present only in small quantities in sheep's urine. The pig's urine, indeed, contains it in larger quantities ; but the percentage is still so small as to justify the statement that the urine of the common farm animals is not a complete manure, and must be supplemented by phosphates, if it is to be used alone. The incomplete nature of urine as a manure constitutes a strong argument in favour of its being applied along with the solid excreta, which

¹ The urine of the pig, from the nature of its food, is, as a general rule, a very poor nitrogenous manure.

contain, as we have seen, considerable quantities of phosphoric acid. It is on this account that the drainings of rotten manure-heaps are more valuable, from a manurial point of view, than urine itself, since these contain the soluble portion of the phosphates in the solid excreta.¹ The urine of all animals, however, is not equally poor in phosphates. In the case of flesh-eating animals, such as the dog, the urine is found to contain them in considerable quantities.

The above tables show that the most valuable urine, weight for weight, is that of the sheep, as it contains the largest amount of alkalies (including potash) and nitrogen; that the urine of the horse comes next; then that of the cow; while, as has already been pointed out, that of the pig is the poorest.

In order to make our survey of the composition of urine uniform with that of the dung, let us see how the urine of the common farm animals compares in the matter of the composition of its dry substance. The following results (basing our calculations on Stoeckhardt's figures, previously given) show this:—

	Nitrogen, per cent.	Phosphoric acid, per cent.	Alkalies, per cent.
Pig . . .	12.0	5	8
Horse . . .	10.9	trace	13.6
Sheep . . .	10.4	3.7	14.9
Cow . . .	10.0	trace	17.5

From these figures we see that the dry substance of the urine of the pig is richest in nitrogen and phos-

¹ See Appendix, Note XV., p. 290.

phoric acid, but poorest in alkalies, of the four common farm animals; that of the horse comes next in the amount of nitrogen it contains, but that, on the whole, there is very little difference between the horse, cow, and sheep in this respect.¹

As in the case of the dung, this subject is best studied in relation to the food consumed. We are again indebted to Wolff's investigations for valuable information on this point. He has found that the following percentages of *organic matter*, *nitrogen*, and *mineral substances*, originally present in the dry matter of the food, are voided in the urine:—

	Cow.	Ox.	Sheep.	Horse.	Average.
Organic matter . . .	4.0	4.4	2.0	3.3	3.4
Nitrogen	31.0	54.8	42.3	60.7	47.2
Mineral substances . .	43.1	34.3	41.0	37.5	39.0 ²

We have now considered briefly the composition of the solid excrements and urine of the common farm animals, and have also enumerated some of the principal causes of the variation in their composition.

The solid excreta consist, as we have seen, of *undigested* food, while the urine contains the manurial ingredients of the food which have been *digested* by the animal system.³ The latter is, weight for weight, as a rule, very much more valuable as a manure than

¹ See Appendix, Note III., p. 280.

² See Appendix, Note XVIII., p. 291.

³ The nitrogen present in the urine, it may be well to point out, is derived from the waste of nitrogenous tissue as well as from nitrogenous matter of the food digested.

the former. From the table given in the Appendix¹ it will be seen that the proportions of the nitrogen and ash-constituents originally present in the food consumed, which are voided in the excrements, vary with different circumstances. Wolff, in summarising his results, points out that, as a rule, the solid and liquid excrements will contain about 46 per cent of the organic matter, 87.3 of the nitrogen, and 98.7 of mineral matter; while the experiments of Lawes and Gilbert at Rothamsted show that, with fattening oxen and sheep and with horses, more than 95 per cent of the nitrogen and 96 per cent or more of the ash-constituents are voided in the manure. The pig retains a larger proportion of the nitrogen—about 85 per cent appearing in the manure—while in the milking-cow only about 75 per cent is returned in the excrements. Generally speaking, we may say that the nitrogen originally present in the food suffers very little loss in passing through the animal system, and that, practically speaking, the ash-constituents suffer no loss whatever.

As to the distribution of the manurial ingredients, much will depend on the nature of the food. Almost invariably more than a *half* of the total nitrogen excreted will be found in the urine, in many cases very much more.² Of the mineral constituents, about a

¹ Note IV., p. 281.

² Warington puts this matter admirably in the following words: "If the food is nitrogenous and easily digested, the nitrogen in the urine will greatly preponderate. If, on the other hand, the food is one imperfectly digested, the nitrogen in the solid excrement may

third on the average may be said to be excreted in the urine. Of this mineral matter it may be noted that nearly all the alkalies (potash and soda), or about 98 per cent, are found in the urine. Of phosphoric acid and lime, on the other hand, there are the merest traces in the urine. Horse-urine, however, is an exception with regard to lime, as it contains about 60 per cent of the lime consumed in the food. For information on the subject of pig-manure the reader is referred to Appendix, Note V.¹

Before passing from this part of the subject, it may be desirable to place before our readers the composition of the dung and urine taken together, so that we may be able to form some idea of their relative value, weight for weight. As the nitrogen constitutes by far the most valuable portion of the manurial ingredients, it will be sufficient if we compare them as to their percentage of this ingredient.

	Water, per cent.	Nitrogen, per cent.	Calculated on dry substance, per cent.	Analyses by
Sheep . . .	67	.91	2.7	Jürgensen.
Horse . . .	76	.65	2.7	Boussingault.
Pig . . .	82	.61	3.4	Boussingault.
Cow . . .	86	.36	2.6	Boussingault.

From these figures we see that, in their natural conform the larger quantity. When poor hay is given to horses, the nitrogen in the solid excrement will exceed that contained in the urine. On the other hand, corn, cake, and roots yield a large excess of nitrogen in the urine" ('Chemistry of the Farm,' p. 137).

¹ See p. 281.

dition, the excreta of the sheep are the most valuable; those of the horse and pig coming next; while those of the cow are the poorest, containing one-third as much nitrogen as those of the sheep, and one-half as much as those of the horse and pig. This difference, however, is due almost entirely to the different percentage of water the excreta of the various animals contain in their natural state; for in the dry state they are seen to contain, with the single exception of the pig, practically the same amount.

In conclusion, then, the important points to be noticed are—

1. That in the passage of the food through the system of the common farm animals, only a very small percentage of the fertilising substances, nitrogen, phosphoric acid, and potash, is assimilated and retained in the animal body; and that, therefore, theoretically at least, the excreta should contain nearly the same amount of fertilising matter as the food originally did.

2. That even in the case of a fattening animal, the loss of fertilising matter sustained by the food in passing through the system is not great.

3. That with regard to the total amount of solid excreta and urine voided, the latter contains, as a rule, more nitrogen than the former; the nitrogen in the urine, further, being more valuable, as it is in a soluble condition.

4. That as regards the distribution of the ash-con-

stituents, *lime*, *phosphoric acid*, and *magnesia* are almost entirely found in the solid excrements ; while the urine contains nearly all the *potash*.

5. That the best results can be expected only when the liquid and solid excreta are used together as a manure.

As the composition of the manure depends so largely on the nature of the food, a table will be found in the Appendix, Note VI.,¹ containing the manurial composition of some of the commoner feeding-stuffs.

3. *Litter*.

We have now to consider the third constituent of farmyard manure—viz., the *litter*, which generally consists of straw.

The uses of the litter, in addition to providing a dry and comfortable bed for the animal, may be briefly summed up as follows:—

1. To absorb and retain the liquid portion of the excreta.

2. To increase the quantity of the manure, and thus secure its more equal distribution when applied to the field than could otherwise be done.

3. To add to its value as a manure, both physically and chemically.

4. To retard and regulate the decomposition of the excreta.

Of course litter also performs a very useful function

¹ See p. 282.

sanitarily, inasmuch as it serves to keep the stall or byre fresher and cleaner, and more free from noxious gases, which it absorbs, than would otherwise be the case.

Straw is almost universally used for this purpose. Besides being one of the bye-products of the farm, it is admirably suited in many ways, both owing to its peculiar shape—its tubular structure being excellently adapted for this purpose—as well as on account of its composition, being largely composed of cellulose, a very absorptive substance. Straw thus possesses considerable absorptive power. In manurial ingredients it is not very rich; for, of the various parts of the ripened plant, straw contains the least percentage of nitrogen and phosphates. This is due to the fact that, as the straw ripens, a considerable proportion of these ingredients passes up from the stalk to the seeds, where they are retained.

Generally speaking, straw may be said to contain not more than *a half per cent* of nitrogen—*i.e.*, 11.2 lb. per ton. Its percentage of nitrogen varies, of course; the recorded analyses¹ for wheat-straw ranging from .22 to .81 per cent, or furnishing an average of .48 per cent—*i.e.*, 10.75 lb. per ton. Barley-straw is somewhat richer in nitrogen, the recorded analyses ranging from .41 to .85 per cent, or giving an average of .57 per cent—*i.e.*, 12.76 lb. per ton; while oat-straw is the richest of the commoner straws, ranging from .32 to

¹ See Heiden's 'Düngerlehre,' vol. ii. p. 58.

1.12 per cent, an average of .72 per cent—*i.e.*, 16.12 lb. per ton.

Of mineral matter, however, straw contains a very much larger percentage, proportionally, than of nitrogen; for, with the exception of phosphates, there is a considerable quantity of inorganic fertilising matter, in the shape of potash, lime, &c., present in

COMPOSITION OF STRAW.¹

	ASH.		COMPOSITION OF ASH.			Number of Analyses.
	Per cent.	Lb. per ton.	Lb. per ton.			
			Potash.	Phos- phoric Acid.	Lime.	
Wheat (winter) . . .	5.54	124.09	18.61	5.05	7.18	8
Wheat (summer) . . .	5.14	115.13	25.76	6.47	7.12	6
Rye (winter)	5.33	119.39	20.61	5.89	9.73	8
Rye (summer)	6.14	137.53	42.41	6.73	10.53	1
Barley	4.90	109.76	26.83	5.75	8.73	8
Oats	5.09	114.01	26.22	4.17	9.12	4

it. Of total ash ingredients, on an average, there are generally about 5 per cent—or 112 lb. per ton. The largest percentage of the fertilising matter in this 5 per cent is potash, which varies in the ashes of the straws of the commoner crops from 30 to 15 per cent. The above table will show the variation in composition of the straws of some of the commoner farm

¹ Heiden's 'Düngerlehre,' vol. i. p. 404.

crops, and may be valuable for purposes of reference. The crops are wheat (winter and summer), barley, oats, and rye (winter and summer), and the amount is also calculated in lb. per ton. The results represent the average of a number of analyses.¹ From the table it will be seen that the percentage of phosphates is, as has already been noticed, very small.

But while straw is well adapted for the purposes for which litter is used, it is not the only substance. Its almost exclusive use as litter is largely owing to the fact that it is a bye-product of the farm.

Loam as Litter.—Generally speaking, any substance which has great absorptive as well as retentive powers for nitrogen and the soluble fertilising matters present in farmyard manure, and whose price is nominal, is well suited for acting as litter. Ordinary loamy soil possesses the above qualifications, and is, besides, a substance to be had for nothing, and, under certain circumstances and in certain countries, is actually used for this purpose, often along with straw. A great objection against loam, however, is that it forms a dirty litter. Moreover, it possesses a very small percentage of fertilising matter. The tendency, consequently,

¹ The following quantities of nitrogen are found in rye, pea, and bean straw :—

			Ranging from per cent.	Average per cent.	Lb. per ton.
Rye-straw	.	.	.30 to .73	.57	12.76
Pea-straw	.	.	.76 to 1.61	1.21	27.10
Bean-straw	.	.	1.15 to 2.62	1.92	43.00

in using ordinary loam, would be to dilute the manure too much, besides retarding fermentation to an undesirable extent. Except, therefore, under very exceptional circumstances, loam is not to be regarded as a good litter.

Peat as Litter.—Some kinds of soil, however, are well suited for this purpose. Of these, the best are those rich in organic matter, the so-called peaty soils. Peat, when dried and freed from any earthy matter, forms an excellent absorbent of the liquid portion of the manure, surpassing in this respect straw itself. It is, further, generally very much richer in nitrogen—some peats having been found to contain between 4 and 5 per cent of nitrogen. In some thirty samples of peat analysed by Professor S. W. Johnson, the percentage of nitrogen varied from .4 to 2.9, giving an average of 1.5 per cent.

While it has a very great capacity for absorbing liquids, it possesses in an unequalled degree the power of retaining the soluble nitrogen compounds. This is undoubtedly one of the most important properties which recommend peat for the purposes of litter.¹

Some interesting experiments on the value of peat-moss as a litter have been recently carried out by Dr Bernard Dyer.² From these experiments Mr Dyer has

¹ Dr J. M. H. Munro recommends the sprinkling of a little finely sifted peat-powder in addition to straw, as an excellent means of preventing loss of volatile ammonia in the fermentation of manure.

² See 'Mark Lane Express,' October 7, 1889, p. 475.

found that both its liquid-absorbing and liquid-retaining powers are very much greater than those of straw. While straw was only able to absorb three times its weight of water, peat-moss was found to absorb nearly ten times its weight. With regard to its water-retaining power, this was also found to be in excess of that of straw. Both these properties are, it need scarcely be pointed out, of very great value in a litter. Another point of interest in these experiments was the respective amounts of nitrogen absorbed and retained by the peat-moss and the straw. It was found that, in this respect, the peat-moss had again an advantage over the straw. Lastly, the manure produced by the peat-moss was shown to be richer in fertilising matter than that produced by the use of straw.¹ These experiments are interesting as demonstrating the fact that in peat-moss we have a substance which is capable of acting as an excellent substitute for the more costly straw, and which might increasingly be used as a fodder with great benefit to the farmer.

Another substance which has been suggested as an excellent litter is the common *bracken-fern*. According to some analyses made by Mr John Hughes, the bracken, especially if cut in a young state, is a substance of considerable manurial value. When dried, it is very much richer in nitrogen, potash, and lime than straw. Its absorbent properties, however, are probably not so great. Where it can easily and cheaply

¹ See Appendix, Note VII., p. 283.

be had, as in many parts of Scotland and Ireland, it might well be used for littering purposes.¹

Dried leaves have also been used as a litter. Autumn leaves, however, contain a very small percentage of fertilising matter. This is due to the fact that the most of their potash, phosphoric acid, and nitrogen pass into the body of the trees at the approach of winter. According to Professor Storer, dried leaves only contain from .1 to .5 per cent potash, .006 to .3 per cent phosphoric acid, and about .75 per cent of nitrogen. Leaves, however, besides being poor in manurial ingredients, make a bad litter, as they ferment but slowly. There is in this fermentation a large quantity of cold sour humic acid formed, which seriously impairs the value of the manure.²

Having now considered the composition of the three separate ingredients of farmyard manure—viz., the *dung* or *solid excreta*, the *urine*, and the *litter*—we are in a position to consider the composition of farmyard manure. In this connection it will be well to consider separately the manures produced by the different farm animals.

¹ For analyses see Appendix, Note VIII., p. 283.

² According to Storer, in a ton of autumn leaves of the best quality there would be 6 lb. of potash, less than 3 lb. of phosphoric acid, and 10 or 15 lb. of nitrogen. Another substance that may be used as a litter is sawdust. This substance is a good absorbent, but is of little value as a manurial substance.

1. *Horse-manure.*

The composition of horse-manure is perhaps the most uniform of all the manures produced by the different farm animals. This is due to the fact that the food of the horse is generally of the same kind, consisting of oats, hay, and straw.

The total excrements voided by a horse in a day have been calculated, according to the average of experiments by Boussingault and Hofmeister, at 28.11 lb., of which only 6.37 lb. consisted of dry matter.¹ These 28.11 lb. contained .18 lb. of nitrogen and .92 lb. of mineral matter. The amount of straw necessary to absorb this amount of excrement may be stated at from 4 to 6 lb. The amounts of nitrogen and mineral matter in 4 lb. of straw are .01 and .23 lb. respectively. The total amount of nitrogen and ash, therefore, in the farmyard manure produced by a horse in one day, would be .19 lb. nitrogen and 1.15 lb. mineral matter; or, if we take the larger quantity of straw, somewhat more.

Taking these figures, we find that the amount of manure produced by a horse in a year will be from

¹ Heiden's 'Düngerlehre,' vol. ii. pp. 34, 66. In Boussingault's experiments the food consisted of 15 lb. *hay*, 4.54 lb. *oats*, and 32 lb. water; the total excrements amounting to 31.16 lb., containing 7.42 lb. dry matter. In Hofmeister's experiments the food consisted of 5.23 lb. *hay*, 6.18 lb. *oats*, 1 lb. *chopped straw*, and 25.57 lb. water; the excrements amounting to 25.07 lb., containing 5.32 lb. dry matter.

11,720 to 12,450 lb. (*i.e.*, from $5\frac{1}{4}$ to $5\frac{1}{2}$ tons),¹ containing from 69 to 73 lb. nitrogen, and from 420 to 460 lb. mineral matter.²

A word or two may be of value regarding the treatment in the stable of horse-manure. The great object to be aimed at is the prevention of loss of valuable fertilising constituents. This loss may be due to two causes. It may be, in the first place, caused by drainage of the soluble matter of the manure; or secondly, it may be due to volatilisation of the volatile constituents.

The first of these two sources of loss depends on the precautions taken in the way of providing a proper impervious flooring to the stable. This source of loss is extremely difficult to prevent, inasmuch as nearly all materials used for flooring absorb a certain percentage of urine. The judicious use of litter, however, will minimise this loss to within a trifling extent.

Dr Heiden states that the amount of straw used as litter for the horse in Germany is from 4 to 6 lb. per day. The quantity should be regulated according to the percentage of water the excreta contain; the more watery excreta requiring naturally a larger quantity of litter. The most eminent authorities on this subject recommend that the amount of litter

¹ This is taking no account of the amount of water which the manure will absorb, and which will probably double the quantity.

² See Appendix, Note IX., p. 283.

should equal one-fourth of the food in its natural state, or about one-third of its dry substance.

The second source of loss, which is due to volatilisation of the volatile ingredients, may be largely prevented by the use of certain preservatives.

Horse-dung being, comparatively speaking, of a dry nature, it is extremely difficult to effect its thorough mixture with the litter. For this reason the manure formed from horse excreta is particularly liable to rapid fermentation.¹ In the process of fermentation, as will be seen more in detail further on, the nitrogen is converted into carbonate of ammonia. As nitrogen in this form is of an extremely volatile nature, the risks of loss from this source are considerable. As illustrating this fact, it may be mentioned that Bous-singault has found by experiment that the total percentage of nitrogen contained by fresh horse-manure might be reduced in the process of fermentation to one-half of its original amount by loss from this source.

The preservatives used to prevent this volatilisation are technically known as "fixers." This they do by chemically combining with the volatile ammonia and forming non-volatile compounds with it.

Of the acid fixers, hydrochloric and sulphuric acids have been recommended. The former, however, is not well suited for this purpose. It is a strongly fuming

¹ The rapid fermentation of horse-manure is due to its mechanical as well as its chemical nature. The horse does not reduce its food to such small pieces, and its urine is rich in nitrogen.

acid, and when brought into contact with ammonia forms dense white fumes. The use of sulphuric acid is not open to this objection. Sulphate of ammonia, the salt formed in this case, is one of the most stable (or least volatile) of the compounds of ammonia. If used, it should be largely diluted with water, and the whole mixed with sand. Such a mixture, when sprinkled over the stable-floor in even very small quantities, has been found to effectually prevent any loss of the volatile carbonate of ammonia.

It is not, however, on the whole advisable to use an acid substance as a fixer, since such a substance may act deleteriously on the horses' hoofs.

Such substances as *gypsum*, *copperas*, and *sulphate of magnesia*, while equally efficient, are not open to this objection. The above-mentioned substances owe their efficacy to the fact that they are compounds of sulphuric acid, which, by combining with the volatile ammonia and forming sulphate of ammonia, prevent its escape.

Gypsum, or sulphate of lime, although, comparatively speaking, an insoluble substance, when brought in contact with carbonate of ammonia has been proved to effect the conversion of the ammonia into sulphate of ammonia. It is also believed to retard the decomposition of the manure.¹ Copperas, or ferrous sulphate, while a soluble salt, and while thus acting in a more speedy manner in fixing the ammonia, is not so well .

¹ Schulze recommends one-third of a pound per day of sulphate of lime for each horse.

suited, owing to the hurtful influence it is well known to possess on plant-life. It is only right to remember that there may be circumstances in which copperas may, in small quantities, act even beneficially as a manure, as Griffiths' experiments would seem to indicate. The above objection, however, cannot be urged against sulphate of magnesia. In addition to fixing the ammonia, sulphate of magnesia may very probably fix the soluble phosphoric acid. Kainit, which consists of a mixture of sulphates and chlorides of potassium and magnesium, has also been suggested for this purpose. By using such a fixer, the value of the resulting manure would be much enhanced. In conclusion, it must be remembered that all the above-named fixers act very much in the same way—viz., by converting the volatile carbonate of ammonia into sulphate of ammonia.¹

2. *Cow-manure.*

The composition of the manure formed from the excrementitious matter of the cow is very much less constant than is the case in the horse-manure. An average statement of that composition is therefore very much more difficult to obtain. The number of analyses available for the purpose of forming this average is, however, very large. The manure produced by cows contains a large percentage of water. This is due to the large quantity of water they drink.

¹ See Appendix, Note X., p. 284.

It has been estimated that milch-cows drink along with their winter food, for every pound of dry substance, 4 lb. of water, and in summer about 6 lb.

According to some experiments by Boussingault, the excrements of a cow in a day amounted to 73.23 lb., of which only 9.92 lb. were dry matter.¹ These excrements contained .256 lb. of nitrogen and 1.725 lb. of mineral matter. The amount of straw necessary to use as litter for this amount of excrements may be taken at 6 to 10 lb. The manure, therefore, formed by a cow per day, would contain from .274 to .286 lb. of nitrogen, and from 2.046 to 2.278 lb. of mineral matter. In a year this would amount to from 100 to 104.4 lb. of nitrogen, and from 746.8 lb. to 831.5 lb. of mineral matter; or from 6 cwt. 75 lb. to 7 cwt. 47 lb.

Cow-dung is, owing to its more watery nature and poorer quality, very much slower in its fermentation than horse-dung. When applied alone, cow-manure is very slow in its action, and makes its influence felt for at least three or four years. It is difficult to spread it evenly over the soil, owing to the fact that, when somewhat dried, it has a tendency to form hard masses, which, when buried in the soil, may resist decomposition for a very long period. The cause of this is due to the presence of a considerable amount of mucilaginous and resinous matter in the solid excreta, which prevents the entrance of moisture and air

¹ The food consisted of 30 lb. *potatoes*, 15 lb. *hay*, and 120 lb. *water*.

into the centre of the mass. This tendency of cow-manure to resist decomposition will be greatly lessened in the case of the excrements of a cow richly fed.

The risks of loss of volatile ammonia are, therefore, in its case not so great as we have seen them to be in the case of the "hot" horse-dung. Notwithstanding this fact, much of what has been said on the use of preservatives for horse-manure may be also applied to the cow-dung. This is owing to the fact that the dung is allowed to accumulate in the court for some time. The amount of straw it is advisable to use as litter varies, as has been said, from 6 to 10 lb. per day. The best method of calculating this amount, according to Dr Heiden, is by taking one-third of the total weight of the dry substance of the food. The above authority also recommends that the straw is best applied in blocks of about one foot in length; and this for the following reasons:—

1. The strewing of it is more convenient. ✓
2. The absorption of the fluid portion is more complete.
3. The cleaning out of the manure from the byre is easier.
4. The manure is more easily distributed when applied to the field.

Among the advantages incidental to allowing the manure to accumulate in the court may be mentioned the following:—

1. The more thorough absorption of the urine by

the straw, and, consequently, the more uniform mixture which will be thus effected of the more valuable urine with the less valuable solid excreta.

2. A certain retardation of decomposition effected by the treading under foot of the manure.

3. The protection of the manure from rain and wind, and the securing of a uniform temperature.

Against those advantages must be placed the risk of seriously affecting the health of the animal. Although this is a point of very great importance, it scarcely falls within the scope of this work. It may be pointed out, however, that the judicious use of some of the chemical fixers previously referred to may do much to keep the air of the byre or court free of noxious gases.¹

3. *Pig-manure.*

The food of the pig is so very variable in its character that it is wellnigh impossible to obtain anything like an average analysis of its excrements. When the food of the pig is rich, then the manure may be quite equal in quality to the other manures. According to Boussingault, the total amount of excrements, on an average, voided by a pig in twenty-four hours is about 8.32 lb., of which 1.5 lb. is dry matter.² The amount of nitrogen these excrements contain is only .05 lb., and of mineral ingredients .313

¹ For further analyses of cow-manure, see Appendix, Note XI., p. 286.

² This is for a pig of six to eight months old, and fed on potatoes.

lb. If we take the amount of straw most suitable for absorbing this quantity of excrementitious matter at from 4 to 8 lb., then we shall find that the manure produced by a pig will contain from .06 to .074 lb. nitrogen and .545 to .772 lb. mineral matter. These quantities, calculated for a year, give from 22 to 27 lb. of nitrogen, and from 1 cwt. 87 lb. to 2 cwt. 57 lb. of mineral matter. That is about as much nitrogen as would be contained in $1\frac{1}{4}$ to $1\frac{1}{2}$ cwt. of nitrate of soda (95 per cent purity); or from slightly less than 1 cwt. to slightly over 1 cwt. of sulphate of ammonia (97 per cent purity).

As has already been pointed out, the excrements of the pig are, as a rule, very poor in nitrogen. This accounts for the fact that pig-manure is a "cold" manure, slow in fermenting.¹

4. *Sheep-manure.*

The dung and the urine of the sheep, as we have already seen, are, weight for weight, the most valuable of any of the common farm animals. The total weight of the excrements voided by a sheep in a day may be taken, on an average,² at 3.78 lb., of which .97 lb. is dry matter. These excrements contain .038 lb. of nitrogen and .223 lb. mineral matter. Tak-

¹ It has been asserted that the use of pig-manure, when applied alone, is apt to give an unpleasant taste to the produce grown.

² Taken from a very large number of analyses by a number of experimenters. See Heiden's 'Düngerlehre,' vol. i. p. 99.

ing the amount of straw most suitable for absorbing this quantity of excrementitious matter at three-fifths of a pound, then the manure produced by a sheep in a day will contain .0429 lb. nitrogen and .264 lb. mineral matter. That is, in a year the quantities of nitrogen and mineral matter in the manure produced by a sheep would be 15.66 lb. of nitrogen and 96.36 lb. of mineral matter.

From its richness in nitrogen, and from its dry condition, sheep-dung is peculiarly liable to ferment. While richer in fertilising substances than horse-manure, it is not so rapid in its fermentation. This is due to the harder and more compact physical character of the solid excreta. The risks of loss of volatile ammonia are, in its case, exceptionally great. The use of artificial "fixers" is therefore to be strongly recommended.¹

¹ See Storer, 'Agricultural Chemistry,' vol. ii. p. 96.

A question of great importance is as to the amount of farmyard manure produced on a farm in a year, and its value. This is a question which is extremely difficult to satisfactorily deal with. Various methods of calculating this amount have been resorted to. It may be well to state these pretty fully. Some practical authorities estimate the amount by calculating that every ton of straw should produce 4 tons of manure. Another method consists in estimating the amount from the size of the farm. Sir John Lawes has calculated the composition of farmyard manure which should be produced in the case of a farm of 400 acres, farmed on the four-course system. He assumes that half of the roots and 100 tons of hay are consumed at the homestead; that the whole of the straw of the corn crops is retained at home as food and litter; that twelve horses have corn equal to 10 lb. of oats per head per day; and that about ten shillings per acre are expended in the purchase of cake for feeding stock. Under these conditions the amount of farmyard manure should be

Fermentation of Farmyard Manure.

Having now considered the nature of the different manures produced by the four common farm animals separately, it is of importance to consider the exact nature of the fermentation, decomposition, or putrefaction which takes place in the manure-heap.

255 tons (or an average of $2\frac{1}{2}$ tons for each of the 100 acres of root-crop) of *fresh undecomposed dung*. (For composition, see Appendix, Note XVII., p. 291.) Another method is by taking, as the data of calculation, the number of cattle, horses, sheep, &c., producing the manure. Lloyd considers that a fattening animal requires 3 tons of straw in the year, and makes about 12 tons of manure. A farmer, therefore, should make 3 tons of manure for every acre of that part of his land which, in the four-course rotation, is put down to turnips.

The last method consists in taking as the data the amount of food consumed and litter used in the production of the manure. Of these methods Heiden considers the last as alone satisfactory and trustworthy. Applying this method to the horse, he shows, from experiments, that a little over 47 per cent of the dry matter of its food has been proved to be voided in the solid and liquid excreta. Taking the average percentage of water in the excreta as about 77.5, the percentage of dry matter in the excreta will be 22.5. That is, every pound of dry matter in the food eaten by the horse yields a little over 2 lb. of excrementitious matter. To this of course must be added the amount of straw used as litter, which may be taken at 6.5 lb.

From these data we may calculate the amount of manure produced in a year by a horse, making certain assumptions as to the amount of work performed. This Heiden does by assuming that a horse works 260 days, of twelve hours each, in the course of a year, or 130 whole days, spending 235 days in the stall. Calculating from the above data, he estimates that a well fed working horse will produce about 50 lb. of manure in a day, or 6.5 tons in a year. Of course this does not necessarily represent all the manure actually produced by the

It is now more than thirty years since Pasteur showed that the fermentation which ensued on keeping a sample of urine was due to the action of a minute organism, for the propagation of which a certain amount of warmth, air, and moisture, as well as

horse, but how much of the remaining portion of the manure actually finds its way to the farm it is impossible to say. According to the 'Book of the Farm,' Division III. p. 98, a farm-horse makes about 12 tons of manure in a year.

It has been calculated that cows void about 48 per cent of the dry matter of their food in the solid and liquid excreta, which contain of water, on an average, 87.5 per cent. That is, every pound of dry matter will furnish 3.84 lb. of total excreta. By adding the necessary amount of straw for litter (which may be taken at one-third the weight of the dry matter of the fodder), Heiden calculates that an ox weighing 1000 lb. should produce 113 lb. of manure in a day, or 20 tons in a year. The 'Book of the Farm,' Division III. p. 98, gives the annual amount at from 10 to 14 tons. According to Wolff, one may assume that on an average the fresh excrements (both liquid and solid) of the common farm animals (with the exception of the pig) contain of every 100 lb. of dry matter in the food consumed about 50 lb., or a half. Estimating the dry matter in the litter used at equal to about $\frac{1}{4}$ of the dry matter of the food, this would mean that for every 100 lb. of dry matter consumed in food there would be 75 lb. of dry manure (viz., 50 lb. dry excrements + 25 lb. dry litter), which would yield 300 lb. of farmyard manure in the wet state—*i.e.*, with 75 per cent water. The amount of food daily required per every 1000 lb. of live-weight of the common farm animals may be taken, roughly speaking, at 24 lb. dry food material and 6 lb. of straw as litter. The daily production of manure for 1000 lb. of live-weight would amount, therefore, to 18 lb. of dry, or 72 lb. wet manure. (See Appendix, Note XVII., p. 291.) According to J. C. Morton and Evershed, oxen feeding in boxes require 20 lb. of straw per head per day as litter. An ox, therefore, will make 8 tons of fresh dung in six months, using 32 cwt. of litter. This means that each ton of litter gives 5 tons of fresh dung. It is calculated that nearly twice as much litter must be used in open yards.

the presence of certain food-constituents, especially nitrogenous bodies, were necessary.

Subsequent researches by Pasteur and others have conclusively demonstrated that the micro-organic life, instrumental in effecting the putrefaction or decay of organic matter of any kind, may be divided into two great classes:—

1. Those which require a plentiful supply of oxygen for their development, and which, when bereft of oxygen, die—known as *aerobies*.

2. Those which, on the contrary, develop in the complete absence of oxygen, and which, when exposed to oxygen, die—known as *anaerobies*.

In the fermentation of the manure-heap, therefore, we must conceive of the two classes of organisms as the active agents. In the interior portion of the manure-heap, where the supply of oxygen is necessarily limited, the fermentation going on there is effected by means of the anaerobic organism — *i.e.*, the organism which does not require oxygen; while on the surface portion, which is exposed to the air, the aerobic (or oxygen-requiring) organism is similarly active. Gradually, as decay progresses, the aerobic organisms increase in number. It is through their instrumentality that the final products of decomposition are largely produced. The functions of the anaerobic organisms may be, on the contrary, regarded as largely preparatory in their nature. By breaking up the complex organic substances in the manure into

new and simpler forms, they advance the process of putrefaction through the initial stages; and when this is accomplished, they die and give place to the aerobic, which, as we have just seen, effect the final transformation of the organic matter into such simple substances as *water* and *carbonic acid gas*.

The conditions influencing the fermentation of farmyard manure may be summed up as follows:¹—

1. *Temperature*.—The higher the temperature the more rapidly will the manure decay.

2. *Openness to the Air*.—Of course it will be seen that the effect of exposing the manure to the action of the air is to induce the development of the aerobic type of organism, and thus to promote more rapid fermentation. If, on the other hand, the manure be impacted, the slower but more regular fermentation, due to the anaerobic type of organism, will be chiefly promoted. It must be remembered that in the proper rotting of farmyard manure both kinds of fermentation should be fostered. It is, in fact, on the careful regulation of the two classes of fermentation that the successful rotting of the manure depends. It must further be remembered that, even with a certain amount of openness in a manure-heap, anaerobic fermentation may take place. This is due to the fact that the evolution of carbonic acid gas, in such a case, is so

¹ It has been calculated that under ordinary circumstances sheep-dung, when allowed to ferment by itself, should do so in about four months, horse-dung in six months, and cow-dung in eight months.

great as to exclude the access of the atmospheric oxygen into the pores of the heap.

3. The *dampness* of the manure-heap is another important influence. This, of course, will act in two ways. First, by lowering the temperature. Where the manure-heap is found to be suffering from "fire-fang," the common method in practice is to lower the temperature by moistening the heap with water. Secondly, it acts as a retarder of fermentation by limiting the supply of atmospheric oxygen, and thus preventing, as we have just seen, aerobic fermentation.

4. The fourth chief influence in regulating fermentation of the manure-heap is its *composition*, and more especially the amount of nitrogen it contains in a soluble form. The rate at which fermentation takes place in any organic substance may be said chiefly to depend on the percentage of soluble nitrogenous matter it contains: the greater this is in amount, the more quickly does fermentation go on. There are always a number of soluble nitrogenous bodies in farmyard manure. These are chiefly found in the urine, such as *urea*, *uric* and *hippuric acids*, and *ammonia* salts.

Products of Decomposition of Farmyard Manure.

The most important of the changes which take place in the rotting of farmyard manure may be briefly enumerated as follows:—

1. The gradual conversion into gases of a large portion of the organic elements in the manure. Of these gaseous

products the most abundant is *carbonic acid gas* (CO_2). It is in this form that the carbonaceous matter which constitutes the chief portion of the manure escapes into the air. Carbon also escapes into the air, combined with hydrogen, in the form of *carburetted hydrogen* or *marsh-gas* (CH_4), a product of the decomposition of organic matter in the presence of a large quantity of water. This gas is consequently found bubbling up through stagnant water. Next to carbonic acid gas, *water* (H_2O) is the most abundant gaseous product of decomposition. The nitrogen present in the manure, in different forms, is converted by the process of decomposition chiefly into *ammonia*, which, combining with the carbonic acid, forms carbonate of ammonia, a very volatile salt. It is to this fact that one of the great sources of loss in the decomposition of farmyard manure is due. If the temperature of the manure-heap be permitted to rise too high, the carbonate of ammonia volatilises. It is probable, also, that a not inconsiderable portion of the nitrogen escapes into the air in the free state. The last of the most important gaseous products of decomposition are *sulphuretted* and *phosphoretted hydrogen*. It is to these gases that much of the smell of rotting farmyard manure is due.

2. The second class of substances formed are *soluble organic acids*, such as *humic* and *ulmic acids*. The function performed by these acids is a very important

one. They unite with the ammonia and the alkali substances in the mineral portion of the manure, forming humates and ulmates of ammonia, potash, &c. It is these ulmates that form the black liquor which oozes out from the manure-heap.

In very rotten farmyard manure traces of *nitric acid* may be found; but it must be remembered that the formation of nitrates is practically impossible under the ordinary conditions of active fermentation of farmyard manure, except perhaps in its very last stages.

3. The third class of changes taking place have to do with the mineral portion of the manure. The result of the formation of so much carbonic and other organic acids is to increase the amount of *soluble* mineral matter very considerably.

Analyses of Farmyard Manure.

It is chiefly to the valuable researches of the late Dr Augustus Voelcker that we owe our knowledge of the composition of old and fresh farmyard manure. All interested in this important question should peruse the original papers on this subject contributed to the 'Journal of the Royal Agricultural Society' by Dr Voelcker. Typical analyses illustrating the variation in the composition of farmyard manure at different stages of decomposition will be found in the Appendix.¹ From what has been already said, it is

¹ See Appendix, Note XII., p. 286.

obvious that the composition of farmyard manure is of a very variable nature.

The quantity of moisture naturally varies most, and this variation will depend on the age of the manure, and the conditions under which it is permitted to decay. It may be taken at from a minimum of 65 per cent in fresh to 80 per cent in well-rotted manure. The total organic matter may be taken at from 13 to 14 per cent, containing nitrogen .4 to .65 per cent. The total mineral matter will range from about 4 to 6.5 per cent, containing of potash from .4 to .7 per cent, and of phosphoric acid from .2 to .4 per cent.¹

As Mr Warington² has pointed out, one ton of farmyard manure would thus contain 9 to 15 lb. of nitrogen, about the same quantity of potash, and 4 to 9 lb. of phosphoric acid. These quantities of nitrogen and phosphoric acid, calculated to (95 per cent) nitrate of soda, and (97 per cent) sulphate of ammonia, and (25 per cent) superphosphate, give respectively 57.25 to 96 lb. nitrate of soda, 45 to 75 lb. sulphate of ammonia, and 35 to 79 lb. superphosphate. That is, in order to apply as much nitrogen to the soil as is contained in one ton of nitrate of soda, we should require to use from 23 to 41 tons of farmyard manure: similarly one ton of sulphate of ammonia contains as much nitrogen as 30 to 50 tons farmyard manure. In

¹ See Heiden's 'Düngerlehre,' vol. ii. p. 156.

² Warington, 'Chemistry of the Farm,' p. 33.

the same way one ton of superphosphate of lime contains as much phosphoric acid as 28 to 64 tons farm-yard manure.

The value of rotten manure is, weight for weight, greater than that of fresh manure. This is due to the fact that, while the water increases in amount, the loss of organic matter of a non-nitrogenous nature more than counterbalances the increase in water. The manure, therefore, becomes more concentrated in quality. The loss on the total weight, according to Wolff, in the rotting of farmyard manure, should not exceed in two or three months' time 16 to 20 per cent—viz., a sixth to a fifth of its entire weight. Not only, however, does the manure become richer in manurial ingredients, but the forms in which the manurial ingredients are present in rotten manure are more valuable, as they are more soluble. These statements must not be taken as proving that it is more economical to apply farmyard manure in a rotten condition than in a fresh one. The distinction must not be lost sight of which exists between relative increase—
increase in the percentage of valuable constituents—and absolute increase. The increase in the value of the manure by the changes of the manurial ingredients from the insoluble to the soluble condition may be effected at the expense of a considerable amount of absolute loss of these valuable ingredients. This is a point which is probably too often left out of account in discussing the relative merits of fresh and rotten

farmyard manure; and it is important that it should be clearly understood. In the words of the late Dr Voelcker: "Direct experiments have shown that 100 cwt. of fresh farmyard manure are reduced to 80 cwt. if allowed to lie till the straw is half rotten; 100 cwt. of fresh farmyard manure are reduced to 60 cwt. if allowed to ferment till it becomes 'fat or cheesy'; 100 cwt. of fresh farmyard manure are reduced to 40-50 cwt. if completely decomposed. This loss not only affects the water and other less valuable constituents of farmyard manure, but also its most fertilising ingredients. Chemical analysis has shown that 100 cwt. of common farmyard manure contain about 40 lb. of nitrogen, and that during fermentation in the first period 5 lb. of nitrogen are dissipated in the form of volatile ammonia; in the second, 10 lb.; in the third, 20 lb. Completely decomposed common manure has thus lost about one-half of its most valuable constituent."¹ While, of course, a very great amount of absolute loss of the valuable constituents—the nitrogen and ash-constituents—of farmyard manure may take place through volatilisation and drainage, by taking requisite precautions this loss may be very much minimised. As regards the total loss, this, in two or three months' time, should only amount to 16 to 20

¹ Recent experiments by Müntz and Girard in France have shown that the loss in sheep excreta from volatilisation of the carbonate of ammonia amounted to over 50 per cent. By the use of straw litter this was reduced to about a half less, and with earth litter one quarter less.

per cent—or one-sixth to one-fifth of the weight.¹ The use of fixers, to which reference has already been made, will greatly minimise this loss. The application of fixers is best made to the manure when still in the stall or byre. The health of the animal benefits by so doing, while the manure is at once guarded against loss from this source.

As to the relative merits of covered and uncovered manure-heaps, much difference of opinion exists. It is one of those questions which does not admit of final decision one way or another, as it depends so largely on the individual circumstances of each case. That manure produced under cover is more valuable than manure made in the open is readily granted. The question, however, is as to whether the increase in its value is sufficiently great to warrant the extra expense involved in building covered courts. This depends on the individual circumstances of each case, and cannot be decided in a general way. For experiments on the relative value of manure made under cover and in the open, see Appendix.²

The method of applying farmyard manure to the field is a question which belongs more to the practical farmer than to the scientist, and must be largely decided by economic considerations. There is an aspect, however, of the question which may well be treated here. The first point in the production of good manure is in

¹ See Appendix, Note XIII., p. 288.

² See Appendix, Note XIV., p. 289.

connection with its even distribution. It is of great importance that the excrements of the different farm animals be thoroughly mixed together. By the intimate incorporation of the "hot" horse-dung with the "cold" cow and pig dung, uniform fermentation is secured. Fire-fang—or too rapid fermentation—may occur from this not being properly done, and from the manure becoming too dry. It is important, also, as we shall see immediately, to have the manure uniform in quality when applied to the field. The manure ought to be firmly trodden down, to moderate the rate of fermentation. Where the manure-heap is exposed to rain, the quantity of water it will naturally receive will probably be quite sufficient, if indeed not too much, to ensure a proper rate of fermentation—except, perhaps, in very warm weather. The great point to be aimed at is to ensure regular fermentation. What has to be especially avoided is any sudden exposure of the manure to large quantities of water. The result of such a washing-out of the soluble nitrogen is to retard fermentation, besides incurring the risk of great actual loss by drainage.¹

Application of Farmyard Manure to the Field.

In applying the manure to the field, and before ploughing it in, two methods of procedure may be pursued. First, the manure may be set out in heaps.

¹ See Appendix, Note XV., p. 290.

larger or smaller, over the field, and be allowed to remain in these heaps some time before being spread; and secondly, it may be directly spread broadcast over the field, and thus allowed to lie for some time. Lastly, the manure may be ploughed in immediately; and it may be stated that such a method is, where circumstances permit, the safest and most economical method.¹

In discussing the merits and demerits of these two methods, Dr Heiden points out, first, with regard to the distribution of the manure in small heaps over the field, that this is not to be recommended, on the following grounds:—

1. Because the chances of loss by volatilisation are thereby increased. The manure is distributed several times instead of only once or twice.

2. It is apt to ensure unequal distribution. The separate heaps run the risk of losing their soluble nitrogenous matter, which soaks into the ground beneath the heaps. The other portions of the field not covered by the manure-heaps are thus manured with washed-out farmyard manure, bereft of its most valuable constituents. The result is, that while certain portions of the field are too strongly manured, other portions are too weakly manured.

¹ For spring application refuse farmyard manure is generally used, because in this condition its fertilising matter is more quickly available. On light land it is best to apply it in the winter condition shortly before it is likely to be used. (See p. 261.)

3. The proper fermentation of the manure is apt to be interfered with by the loss of that which is its most important agent—viz., the soluble nitrogenous matter—and also by the drying action of the wind.

The same objections hold good to a large extent with regard to the setting out in the fields of the manure in large heaps. The risks of loss, in one respect, may be said to be less, owing to the smaller surface presented. On the other hand, they may be greater, owing to fermentation taking place more quickly. Agricultural practice, however, often renders this custom necessary; and if precautions are taken not to let the heap lie too long, and to cover it over with earth, the risk of serious loss may be rendered inconsiderable.

With regard to the second method of procedure—viz., the spreading of the manure broadcast over the field, and allowing it thus to lie—Dr Heiden is of opinion that this should only be done when the field is level. In the case of uneven ground the risks are, of course, obvious. It has been affirmed that, by allowing farmyard manure thus to lie exposed for some time, an important loss of volatile ammonia—carbonate of ammonia—is apt to take place. This could only take place where the former treatment of the farmyard manure had been bad. Hellriegel has shown that in the case of properly prepared farmyard manure there is no danger of loss in this way. The absorptive power of the soil for ammonia, it must be remem-

bered, is very great, and the amount of volatile ammonia in farmyard manure is relatively so small that it is scarcely possible that any could escape in this way. Hellriegel's experiments have demonstrated this in a very striking way. He has found that in the case of a chalky soil, and during the summer and autumn months, practically no loss of ammonia takes place. The following considerations may be further urged in support of this method of application, as against immediately ploughing in the manure, viz.:—

1. That fermentation takes place more quickly.
2. That it results in a more equable distribution of the manurial constituents in the dung, by gradually and thoroughly incorporating the liquid portion of the manure with the soil-particles.

Against, however, these undoubted advantages, one serious disadvantage may be urged — viz., that the manure, before being ploughed in, becomes robbed to a large extent of its soluble nitrogenous compounds, which, as we have repeatedly observed, are so necessary for fermentation; and that, therefore, when it is ploughed in, it does not so readily ferment. This being so, it is highly advisable, in the case of light or sandy soils, not to follow such a practice, but to plough the manure directly in.

As to the depth to which it is advisable to plough the manure in, it may be here noticed that it should not be too deep, so as to permit of the access of suffi-

cient moisture to ensure proper fermentation, and to prevent rapid washing down of nitrates to the drains. Lastly, it need scarcely be pointed out that it is highly important to have the manure evenly and thoroughly incorporated with the soil-particles. Where the manure is permitted to cake together in lumps, it may successfully resist the action of fermentation for several years.

Value and Function of Farmyard Manure.

Practical experience has long demonstrated the fact that farmyard manure is, taking it all round, the most valuable, and admits of the most universal application, of all manures; and science has done much to explain the reason of this. The influence of farmyard manure is so many-sided that it is difficult even to enumerate its different functions. As has already been pointed out, its indirect value as a manure is probably as great as, if indeed even not greater than, its direct value. In concluding our study of farmyard manure, we shall endeavour to summarise, in as brief a manner as possible, its chief properties.

First, as to its value as a supplier of the necessary elements of plant-food. This, there can be little doubt, has been, and still is, grossly exaggerated by the ordinary farmer. Much has been claimed for it as a "general" manure. How far it merits pre-eminence on this score among other manures will be seen in the

sequel. It is true that, since it is composed of vegetable matter, it contains all the necessary plant ingredients.¹ As has been shown in the Introduction, there is practically in the case of most soils no necessity to add to a manure any more than the three ingredients, *nitrogen*, *phosphoric acid*, and *potash*. Its value, then, as a direct manure, must depend on the quantity and proportion in which these three ingredients are present. These substances, as we have already seen, it contains only in very small quantities. It is, judged from this point of view, a comparatively poor manure. Furthermore, only a certain percentage of these substances is in a soluble or immediately available condition,—in this respect the rotten manure being very much more valuable than the fresh manure.

Again, a point of great importance in a universal manure is the proportion in which the necessary plant-foods are present. If it be asked, Are the nitrogen, phosphoric acid, and potash in farmyard manure present in the proportion in which crops require these constituents? the answer must be in the negative. Heiden² has very strikingly illustrated this point, in so far as the relations between the two ash ingredients are concerned, by some computations as to the amount which would be removed from the soil in the course of

¹ The total amount of plant-food in a ton of farmyard manure is together less than 1-20th of its total weight.

² See Heiden's 'Düngerlehre,' vol. ii. p. 171.

different rotations.¹ In the case of five different rotations it was found that the ratio between the potash and phosphoric acid removed was as follows:² (1) 2.96 to 1; (2) 2.76 to 1; (3) 2.95 to 1; (4) 4.13 to 1; (5) 3.78 to 1. This would give a mean of 3.32 to 1. This is not the ratio in which these ingredients are generally present in farmyard manure. Farmyard manure may be said to be much richer in the mineral constituents of plants than in nitrogen. Professor Heiden found that in the case of a farm at Waldau, the crops in the course of ten years removed from a *morgen* (.631 of an acre) the following quantities:—

	lb.
Nitrogen	329
Potash	263
Phosphoric acid	121

In order to supply these amounts the following quantities of manure would require to be supplied:—

1. For the nitrogen, 26 or 27 tons (manure containing .606 per cent nitrogen).
2. For the potash, 20 to 25 tons (manure containing .672 per cent potash).
3. For the phosphoric acid, 13 to 19 tons (manure containing .315 per cent phosphoric acid).

From the above it will be seen that farmyard man-

¹ For full details see Appendix, Note XVI., p. 290.

² Storer reproduces these results in his 'Agricultural Chemistry,' vol. ii. p. 21.

ure contains too little nitrogen in proportion to its ash ingredients.

It is not merely the amount of fertilising ingredients removed by the crop we have to take into account in estimating the value of certain manurial ingredients for the different crops. Two other considerations have to be remembered—viz., the amount of the constituents already present in the soil, and the ability of the different crops to obtain the ingredients from the soil. If we take into account these two considerations in estimating the value of farmyard manure as a general manure, we shall find that they accentuate the inadequacy of the ratio existing between the nitrogen and the mineral ingredients. Messrs Lawes and Gilbert have found in the Rothamsted experiments with farmyard manure, that while it restored the mineral ingredients, it was inadequate as a sufficient source of nitrogen. Nitrogen is, of all manurial ingredients, in least abundance in soils. It is consequently found that the ingredient in which farmyard manure requires to be reinforced is nitrogen. With regard to phosphoric acid and potash, it has already been shown that the ratio between them is probably greater than that in a good average manure. We should, arguing from this alone, be inclined to think that farmyard manure would be best reinforced with potash. The reverse is the case, however, as every farmer knows. This is due, first, to the fact that the potash, unlike the phosphoric acid, is entirely of a soluble nature, and therefore

immediately available for the plant's needs; and secondly, to the fact that the necessity for the application of potash as a manure is generally not nearly so great as in the case of phosphoric acid. The result is, that farmyard manure will be, as a rule, more valuably supplemented by phosphoric acid than by potash.

Another point of great importance, in estimating the value of farmyard manure as a chemical manure, is the inferior value possessed by much of the nitrogen it contains, as compared with the nitrogen in such artificial manures as nitrate of soda and sulphate of ammonia. According to the Rothamsted experiments, weight for weight, the nitrogen in farmyard manure is not half so valuable as it is in sulphate of ammonia. Much of the nitrogen becomes only very slowly available; not a little of it perhaps actually takes years to be converted into nitrates.¹

¹ This aspect of farmyard manure has been ably stated by Mr F. J. Cooke, a well-known Norfolk farmer. In commenting on the results of the Rothamsted experiments, he says: "It is clear enough that the faith of the farmer in the soil-enriching character of his home-made manure is amply justified; the only question being, indeed, if this quality be not too highly appreciated. It is not, after all, so much by the fattening of our land as by the bounty of the crop grown upon it that we reap the fruit of our exertions. The man of scientific mind keeps his purpose fixed on the *production of good crops* mainly, and the cheapest way to grow them. The experiments under consideration show that richness of land may be purchased much too dearly, and that richness of crop by no means bears the necessary relation to richness of soil which has sometimes been imagined. We may boast of the 'lasting qualities' of our dung, but the answer of

Thus, with regard to the direct value of farmyard manure as a manure, we have seen—

1. That it contains a very small quantity of the three fertilising ingredients.
2. That the proportion in which these three ingredients are present is not the best proportion for the requirements of crops.
3. That the form in which a portion of these ingredients—nitrogen and phosphoric acid—is present is not of the most valuable kind.

It is consequently not as a direct chemical manure that farmyard manure is pre-eminently valuable. We must seek for perhaps its most valuable properties in its indirect influence.

It adds to the soil a large quantity of organic matter. Most soils are improved by the addition of *humus*. The water-absorbing and retaining powers of a soil are increased by this addition of *humus*, while it enables the soil to attract an increased amount of moisture from the air. This is often of great importance, as in the period of germination of seed.¹ The influence it exerts on the texture of the soil in the process of

science by these experiments is, that so great is the last that the life of one man may not be long enough to exhaust it. In the extravagant use of dung, therefore, such considerations, amongst many others, as length of purse, as well as length and character of tenure, must clearly be taken into account."

¹ See paper on "Manurial Experiments with Turnips" by author, in 'Transactions of the Highland and Agricultural Society of Scotland,' 1891.

fermentation is also very great. This is especially so in soils whose texture is too close, such as heavy clayey soils. It opens up their pores to the air, and renders them more friable. Where such an influence is most required, as in clayey soils, the manure ought to be applied in a fresh condition, so that the maximum influence exerted by the manure in this direction may be experienced. On light soils, on the contrary, whose friability and openness are already too great, and which do not require to be increased, the manure will be best applied in a rotten condition. It adds, further, greatly to the heat of the soils by its decomposition. Thus on cold damp soils it effects one very marked benefit. The influence it exerts in its decomposition upon the fertilising ingredients present in the soil is also by no means inconsiderable. In the process of its fermentation large quantities of carbonic acid gas are generated. This carbonic acid probably acts in a double capacity. It will, in the first place, greatly increase the solvent power of the soil-water, and thus enable it to set free an increased amount of mineral plant-food; and secondly, it will help to conserve a certain quantity of the soil-nitrogen, by preventing its conversion into nitrates.

As its indirect and mechanical properties are greatest when in its fresh condition, it will be better to apply it in that condition to soils most lacking in these mechanical properties. We may therefore say that farmyard manure is best applied in a rotted condition

to light sandy soils, and to soils in a high state of cultivation, where its mechanical properties are not so much required.

An important point still remains to be discussed—viz., the rate at which the farmyard manure should be applied. This, of course, should naturally depend on a variety of circumstances—the amount of artificial manures used as supplementary to the farmyard manure, the frequency of its application, and the nature of the soil.

These considerations naturally vary so much, that the quantities of farmyard manure it is advisable to apply in different cases are widely different. There is a strong probability that the rate at which farmyard manure has been applied in the past has been grossly in excess of what could be profitably employed. Opinion is gaining ground among practical farmers, that smaller and more frequent applications of farmyard manure to the soil would be fraught with better results than the older custom of applying a large dressing at a time. This is an opinion in the support of which science can urge strong arguments. It is only of late years that we have come to recognise sufficiently the various risks which all fertilisers are subject to in the soil, and the importance, therefore, of minimising these risks as much as possible by putting into the soil at one time only as much manure as it is safely able to retain.

“The famous old German writer Thaer regarded 17

or 18 tons as an abundant dressing; 14 tons he called good, and 8 or 9 tons light. Other German authorities speak of 7 to 10 tons as light, 12 to 18 tons as usual, 20 or more tons as heavy, and 30 tons as a very heavy application.”¹

In the new edition of Stephens’ ‘Book of the Farm,’² from 8 to 12 tons per acre for roots, and from 15 to 20 tons for potatoes, along with artificials, which may cost from 25s. to 60s. per acre additional, are quoted as general dressings.

The majority of recent experiments with farmyard manure would seem to indicate that, even in the case of what are considered small dressings, the extra return in crop the first year after application is not such as to cover the expense of the manure. Of course, as is commonly pointed out, the effect of farmyard manure is of a lasting nature, and is probably felt throughout the whole rotation, or even longer. This, to a certain extent, is no doubt true; still it may be strongly doubted whether farmyard manure is, after all, an economical manure, as compared with artificial manures. The desirability of manuring the soil and not the crop is, in this age of keen competition, no longer believed in; and the Rothamsted experiments have shown that it is highly doubtful whether even the soil benefits to anything like a commensurate extent by the application of large quantities of farmyard manure.

¹ Storer’s ‘Agricultural Chemistry,’ vol. i. p. 498.

² Division III. p. 130.

This is of course assuming for farmyard manure the value that it would fetch when sold, or, to put it rather differently, the price it would cost if the farmer had to purchase it. Farmyard manure is a necessary by-product of the farm, and can scarcely be regarded, therefore, in the same light as the artificial manures which the farmer buys.¹

¹ Mr F. J. Cooke, who has already been quoted, has kindly furnished the author with his views on the peculiar functions of farmyard manure as a manure. He says: "I look upon it, broadly speaking, as chiefly of value in restoring to good land, after cropping, those particular advantages which good land alone can give, and in helping better than any other manure, when applied to poor land, to bring it up to the level of good land in those particular merits which belong alone to fine soils. I speak now of an inherent value in good soils, beyond that attaching to them as mere reservoirs of abundant plant-food. For instance, one may supply a poor soil by artificial manure with much more food—and in a highly soluble condition—than is needed by the crop to be grown upon it, and yet not get so good a crop as upon a naturally richer but otherwise similar soil less abundantly filled with immediately available food. This may arise from a more perfect distribution of the plant-food in the rich soil, or from the steady way in which it becomes available to the crop, as well as for other reasons. But whatever the cause, there, I think, is the broad fact of the power of farmyard manure to enrich poor soils, so to speak, more naturally—that is, in a way which makes them more nearly correspond to better soils than artificial manures can."

Hence the indirect benefit to the farmer from farmyard manure is probably greater than its direct value as a mere manure. And the usual provision and use of it amongst all straw-growing farmers is sufficiently justified. The extent, however, to which that course may be beneficially carried, is one of the most important of the many difficult economic and scientific problems which the farmer has to face.

On the economic side must of course be considered the cost of manufacture in individual instances, as ruled by the market value of

the straw, and the different circumstances and conditions under which the various farm animals are kept and fed (I have the figures by me of one well-known farmer, which show the cost to him of every ton of home-made manure to be 20s. or more); the price the resultant crops may be expected to command; the cost at the moment of artificial manures, &c., &c. Whilst on the scientific side must be considered the nature of the soil, the particular rotation of crops, &c.

It was, amongst others, just these scientific and yet very definite and practical problems we have tried to throw light on in the series of field experiments conducted for several years by the Norfolk Chamber of Agriculture. (See reprint of summary of same in last year's Report of the Board of Agriculture.)

APPENDIX TO CHAPTER VII.

NOTE I. (p. 225).

DIFFERENCE IN AMOUNT OF EXCRETA VOIDED FOR
FOOD CONSUMED.

WITH regard to the difference in the composition of the solid excreta voided by different fattening animals fed on the same amount of food, see Warington's 'Chemistry of the Farm,' p. 125, where it is shown that for equal amount of live-weight, the sheep produces on the same weight of dry food very much more manure than the pig, while the ox produces even more than the sheep. Of course this does not refer to the total amount of manure produced by the different animals, but only to the amount of manure produced from the consumption of equal quantities of food. This would seem to be owing to the greater capacity the pig has for assimilating its food.

NOTE II. (p. 227).

SOLID EXCRETA VOIDED BY SHEEP, OXEN, AND COWS.

To contrast with the analyses given by Stoeckhardt, it may be well to cite those based on Lawes and Gilbert's experiments, and quoted by Warington ('Chemistry of the Farm,' p. 138):—

I.—SHEEP (fed on *meadow-hay*).

						SOLID EXCREMENT.	
						Fresh.	Dry.
Water	.	.	.	.	.	66.2	...
Organic matter	.	.	.	.	.	30.3	89.6
Ash	.	.	.	.	.	3.5	10.4
						<hr/>	<hr/>
Nitrogen	.	.	.	.	.	.7	2.0

II.—OXEN (fed on *clover-hay* and *oat-straw*, with 8 lb. beans per day).

						Fresh.	Dry.
Water	.	.	.	.	.	86.3	...
Organic matter	.	.	.	.	.	12.3	89.7
Ash	.	.	.	.	.	1.4	10.3
						<hr/>	<hr/>
Nitrogen	.	.	.	.	.	.3	1.9

III.—Cows (fed on *mangels* and *lucerne hay*).

						Mangels.	Lucerne hay.
Water	.	.	.	.	.	83.00	79.70
Nitrogen	.	.	.	.	.	.33	.34
Phosphoric acid	.	.	.	.	.	.24	.16
Potash	.	.	.	.	.	.14	.23

NOTE III. (p. 232).

URINE VOIDED BY SHEEP, OXEN, AND COWS.

The following are the results for urine, the animals being fed as in Note II. :—

		SHEEP.		OXEN.	
		Fresh.	Dry.	Fresh.	Dry.
Water	.	85.7	...	94.1	...
Organic matter	.	8.7	61.0	3.7	63.0
Ash	.	5.6	39.0	2.2	37.0
		<hr/>	<hr/>	<hr/>	<hr/>
Nitrogen	.	1.4	9.6	1.2	20.6
		Cows.			
				Mangels.	Lucerne hay.
Water	.	.	.	95.94	88.25
Nitrogen	.	.	.	.12	1.54
Phosphoric acid	.	.	.	.01	.006
Potash	.	.	.	.59	1.69

NOTE IV. (p. 233).

PERCENTAGE OF FOOD VOIDED IN THE SOLID AND LIQUID EXCREMENTS.

According to Wolff, the following table shows the percentage of the dry substance of the food which is voided in the solid and liquid excrements of the cow, ox, sheep, and horse:—

	Cow.	Ox.	Sheep.	Horse.	Average.
Solid excreta .	38.0	44.0	42.6	46.7	42.8
Urine .	5.8	6.3	6.8	5.7	6.2
Total .	43.8	50.3	49.4	52.4	49.0

NOTE V. (p. 234).

PIG EXCREMENTS.

The excrements voided by pigs are poor in manurial constituents, because the food on which they are fed is generally of a very poor nature. In their case the urine is always very much richer in manurial ingredients than the solid excreta. The relative composition of the solid excreta and the urine will be best illustrated by quoting some experiments carried out by Wolff on this subject. The experiments were carried out with two pigs nine and a half months old, and each 121.9 kilogrammes (a kilogramme is equal to about $2\frac{1}{4}$ lb.) in weight. The first consumed daily 1000 grammes of barley, 5000 grammes of potatoes, and 2572 grammes of sour-milk. The second one consumed the same quantities of potatoes and sour-milk as the first, and 1000 grammes of peas. The following table gives the results of excreta and urine daily voided, in grammes:—

		Dry substance.	Nitrogen.	Ash.	Potash.	Lime.	Magnesia.	Phosphoric acid.
Solid excreta	I.	217.7	8.7	28.6	7.3	4.4	3.0	10.3
	II.	161.1	9.1	31.1	5.9	4.9	2.8	11.1
Urine	I.	112.8	19.3	56.2	33.0	0.4	0.9	6.7
	II.	137.7	30.6	62.2	37.1	0.2	1.1	7.1

NOTE VI. (p. 236).

MANURIAL CONSTITUENTS IN 1000 PARTS OF ORDINARY FOODS.

Based on Lawes and Gilbert's Analyses.

(Warington's 'Chemistry of the Farm,' p. 139.)

	Dry matter.	Nitrogen.	Potash.	Phosphoric acid.
Cotton-cake, decorti- cated }	918	70.4	15.8	30.5
Rape-cake . . .	887	50.5	13.0	20.0
Linseed-cake . . .	883	43.2	12.5	16.2
Cotton-cake, unde- corticated }	878	33.3	20.0	22.7
Linseed . . .	882	32.8	10.0	13.5
Palm-kernel meal, } English }	930	25.0	5.5	12.2
Beans . . .	855	40.8	12.9	12.1
Peas . . .	857	35.8	10.1	8.4
Malt-dust . . .	905	37.9	20.8	18.2
Bran . . .	860	23.2	15.3	26.9
Oats . . .	870	20.6	4.8	6.8
Rice-meal . . .	900	19.1	6.1	23.8
Wheat . . .	877	18.7	5.2	7.9
Rye . . .	857	17.6	5.8	8.5
Barley . . .	860	17.0	4.7	7.8
Maize . . .	890	16.6	3.7	5.7
Brewers' grains . . .	234	7.8	0.4	3.9
Clover-hay . . .	840	19.7	18.6	5.6
Meadow-hay . . .	857	15.5	16.0	4.3
Bean-straw . . .	840	13.0	19.4	2.9
Oat-straw . . .	857	6.4	16.3	2.8
Barley-straw . . .	857	5.6	10.7	1.9
Wheat-straw . . .	857	4.8	6.3	2.2
Potatoes . . .	250	3.4	5.8	1.6
Swedes . . .	107	2.2	2.0	0.6
Carrots . . .	140	2.1	3.0	1.1
Mangels . . .	120	1.8	4.6	0.7
Turnips . . .	80	1.6	2.9	0.8

NOTE VII. (p. 241).

ANALYSES OF STABLE-MANURE, MADE RESPECTIVELY WITH
PEAT-MOSS LITTER AND WHEAT-STRAW (by BERNARD
DYER, B.Sc.)

	Peat-moss litter.	Wheat-straw.
	Per cent.	Per cent.
Total nitrogen	0.88	0.61
Equal to ammonia . . .	1.07	0.74
Phosphoric acid	0.37	0.43
Equal to Tribasic phosphate of lime (or Tricalcic phosphate)	0.80	0.94
Potash	1.02	0.59

NOTE VIII. (p. 242).

ANALYSES OF BRACKEN (by J. HUGHES, F.C.S.)

	No. 1. Young fern.	No. 2. Old fern.
	Per cent.	Per cent.
Water	11.66	14.90
* Organic matter	83.38	80.54
† Mineral matter	4.96	4.56
	<u>100.00</u>	<u>100.00</u>
Containing—		
* Nitrogen	2.42	0.90
† Silica	1.60	2.81
Potash	1.15	0.10
Soda	0.64	0.26
Lime	0.44	0.62
Magnesia	0.13	0.47
Phosphoric acid	0.60	0.30

NOTE IX. (p. 244).

ANALYSES OF HORSE-MANURE.

For a fuller discussion of this question, the reader is referred to Heiden's 'Düngerlehre,' vol. ii. p. 185, and also to Storer's 'Agricultural Chemistry,' vol. i. p. 575.

The statements in the different text-books as to the quantity of manure produced by the horse are such as naturally to perplex the student. This discrepancy is due, however, to the different methods adopted by different writers of calculating this amount. The subject is further discussed in the footnote to p. 252. The following analyses of horse-manure may be valuable for reference. They are taken from Storer's 'Agricultural Chemistry,' vol. i. p. 496:—

	1.	2.	3.	4.	5.	Average.
Water	75.76	69.30	67.23	72.13	71.30	71.15
Dry matter . .	24.24	24.82	32.72	27.87	28.70	27.67
Ash ingredients .	5.07	5.05	6.49	3.37	3.30	4.65
Potash	0.51	0.63	0.22	0.59	0.53	0.49
Lime	0.30	0.74	0.17	0.41	0.21	0.36
Magnesia . . .	0.19	0.29	0.20	0.17	0.14	0.20
Phosphoric acid .	0.41	0.67	0.35	0.12	0.28	0.36
Ammonia	0.26	0.12	0.15	0.44	...	0.24
Total nitrogen .	0.53	0.69	0.47	0.67	0.58	0.59

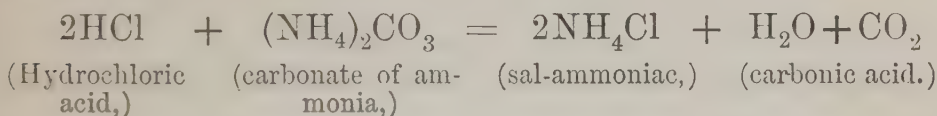
NOTE X. (p. 247).

THE NATURE OF THE CHEMICAL REACTIONS OF AMMONIA "FIXERS."

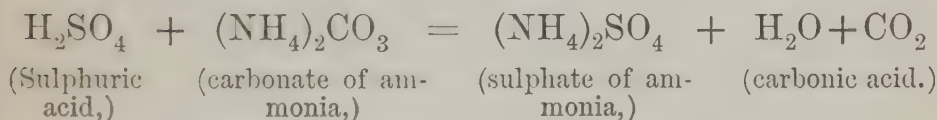
For the student, the exact nature of the chemical reactions taking place may be of interest.

In the first place, it must be distinctly understood that the form in which ammonia escapes from the manure-heap is not, as is so commonly erroneously stated in agricultural text-books, as "free" ammonia. Whenever ammonia is brought into contact with carbonic acid, carbonate of ammonia is formed. When it is remembered that carbonic acid is by far the most abundant of the gaseous products of the decomposition of organic matter, it will be at once seen that free ammonia could not exist under such circumstances.

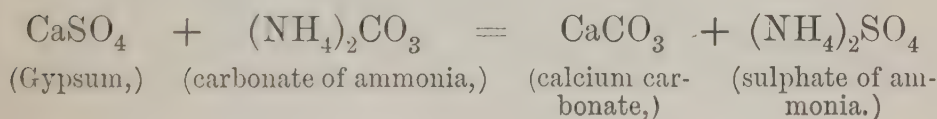
1. In the case of *hydrochloric acid*, the following chemical equation will represent the nature of the reaction—



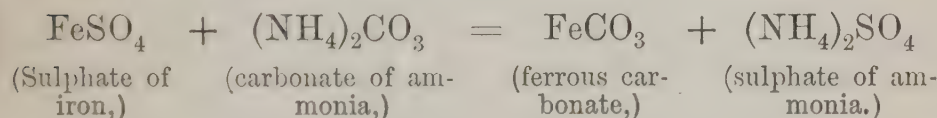
2. In the case of *sulphuric acid*, the equation will be—



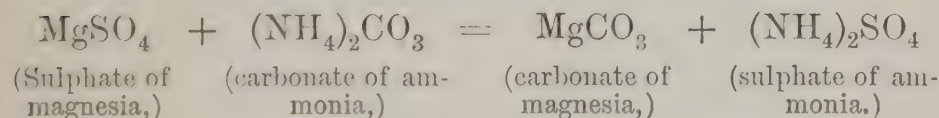
3. With *gypsum* (CaSO_4)—



4. With *copperas* (FeSO_4)—



5. With *sulphate of magnesia* (MgSO_4)—



Reference has been made to the fact that magnesium sulphate may probably not only fix the ammonia, but the phosphoric acid. When magnesium sulphate, soluble phosphoric acid, and ammonia are brought in contact with one another, the double insoluble phosphate of ammonium and magnesium ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{Aq}$) is formed. While such a reaction is possible, it is highly improbable that it takes place to any extent. The double phosphate is a crystalline salt which only separates after a considerable time, and in the presence of a large excess of ammonia.

NOTE XI. (p. 250).

ANALYSES OF COW-MANURE.¹

	1.	2.	3.	4.	5.	6.	Average.
Water . . .	85.30	77.71	74.02	72.87	75.00	77.50	77.06
Dry matter . .	14.70	22.30	25.98	27.13	25.00	22.50	22.93
Ash ingredients	2.04	4.71	3.94	6.70	6.22	2.20	4.30
Potash . . .	0.36	0.46	0.56	1.69	0.39	0.40	0.64
Lime . . .	0.29	0.37	0.58	0.41	0.24	0.31	0.48
Magnesia . .	0.19	0.11	0.13	...	0.18	0.11	...
Phosphoric acid	0.16	0.13	0.07	0.20	0.14	0.16	0.14
Ammonia . .	0.06	0.16	0.07	...	0.27	...	0.14
Total nitrogen .	0.38	0.54	0.41	0.79	0.46	0.34	0.48

NOTE XII. (p. 259).

COMPOSITION OF FRESH AND ROTTEN FARMYARD
MANURE (VOELCKER).

Composition of fresh manure, composed of horse, cow,
and pig dung, about fourteen days old:—

Water	66.17
* Soluble organic matter	2.48
Soluble inorganic matter	1.54
† Insoluble organic matter	25.76
Insoluble inorganic matter	4.05
	<hr/> 100.00 <hr/>
* Containing nitrogen . . . . .	.149
Equal to ammonia . . . . .	.181
† Containing nitrogen . . . . .	.494
Equal to ammonia . . . . .	.599
Total percentage of nitrogen . . . . .	.643
Equal to ammonia . . . . .	.780
Ammonia in a volatile state . . . . .	.034
Ammonia in form of salts . . . . .	.088

¹ Storer's 'Agricultural Chemistry,' vol. i. p. 496.

Composition of the whole ash :—

Soluble in water, 27.55 per cent :—

Soluble silica	4.25
Phosphate of lime	5.35
Lime	1.10
Magnesia	0.20
Potash	10.26
Soda	0.92
Chloride of sodium	0.54
Sulphuric acid	0.22
Carbonic acid and loss	4.71

Insoluble in water, 72.45 per cent :—

Soluble silica	17.34
Insoluble silicious matter	10.04
Oxide of iron and alumina with phosphates	8.47
(Containing phosphoric acid, 3.18 per cent.)	
(Equal to bone-earth, 6.88 per cent.)	
Lime	20.21
Magnesia	2.56
Potash	1.78
Soda	0.38
Sulphuric acid	1.27
Carbonic acid and loss	10.40

 100.00

Composition of rotten dung, six months old, is as follows :—

Water	75.42
* Soluble organic matter	3.71
Soluble inorganic matter	1.47
† Insoluble organic matter	12.82
Insoluble inorganic matter	6.58

 100.00

* Containing nitrogen . . . . .	.297
Equal to ammonia . . . . .	.360
† Containing nitrogen . . . . .	.309
Equal to ammonia . . . . .	.375
Total amount of nitrogen . . . . .	.606
Equal to ammonia . . . . .	.735
Ammonia in a volatile state . . . . .	.046
Ammonia in form of salts . . . . .	.057

Composition of the whole ash:—

Soluble in water, 18.27 per cent:—

Soluble silica	3.16
Phosphate of lime	4.75
Lime	1.44
Magnesia	0.59
Potash	5.58
Soda	0.29
Chloride of sodium	0.46
Sulphuric acid	0.72
Carbonic acid and loss	1.28

Insoluble in water, 81.73 per cent:—

Soluble silica	17.69
Insoluble silica	12.54
Phosphate of lime . . . . .	...
Oxides of iron alumina with phosphates (Containing phosphoric acid, 3.40 per cent.) (Equal to bone-earth, 7.36 per cent.)	11.76
Lime	20.70
Magnesia	1.17
Potash	0.56
Soda	0.47
Chloride of sodium . . . . .	...
Sulphuric acid	0.79
Carbonic acid and loss	16.05
	<hr/>
	100.00

NOTE XIII. (p. 263).

COMPARISON OF FRESH AND ROTTEN MANURE (WOLFF).

	Fresh.	Moderately rotten.
	(Taking the quantity of dry matter as the same.)	
Dry matter	25.00	25.00
Ash	3.81	4.76
Nitrogen	0.39	0.49
Potash	0.45	0.56
Lime	0.49	0.61
Magnesia	0.12	0.15
Phosphoric acid	0.18	0.23
Sulphuric acid	0.10	0.13
Silica	0.86	1.08

NOTE XIV. (p. 263).

LORD KINNAIRD'S EXPERIMENTS.¹

“ Lord Kinnaird has given the particulars of a very careful experiment. He tried to test the comparative value of manure kept in an open court with that kept under cover. He selected the same kind of cattle, gave them the same kind and quantity of food, and bedded them with the same kind of straw. A field of 20 acres of uniform land was selected. This having been equally divided, 2 acres out of each 10 gave the following results:—

Potatoes grown with Uncovered Manure.

				Tons.	cwt.	lb.
First measurement—	1 acre	produced .		7	6	8
Second	do.	do. do. .		7	18	99

Potatoes grown with Covered Manure.

First measurement—	1 acre	produced .		11	17	56
Second	do.	do. do. .		11	12	26

This shows an increase of about 4 tons of potatoes per acre with the covered manure.

“ The next year the weather was wet, grain soft and not in very good order, but the following was the amount of produce:—

Wheat grown with Uncovered Manure.

Acre.	Produce in grain.		Weight per bushel.	Produce in straw.	
	bushels.	lb.	lb.	stones.	lb.
First .	41	19	61½	152	of 22
Second .	42	38	61½	160	of 22

Wheat grown with Covered Manure.

First .	53	5	61	220	of 22
Second .	53	47	61	210	of 22”

¹ Scott's 'Manures and Manuring,' p. 19.

NOTE XV. (pp. 231, 264).

DRAININGS OF MANURE-HEAPS.

The importance of not separating the liquid portion from the solid portion has already been pointed out in dealing with the composition of the solid excreta and the urine. These two constituents of the manure are complementary to one another, and the value of farmyard manure as a general manure is very much impaired if the liquid portion is not applied along with the solid. In one important respect do the drainings of manure-heaps differ from urine—that is, in the percentage of phosphates they contain, the latter being practically devoid of phosphoric acid.

The following is an analysis of drainings from a manure-heap (Wolff):—

Dry substance . . .	18.0	Magnesia . . .	0.4
Ash . . .	10.7	Phosphoric acid . .	0.1
Nitrogen . . .	1.5	Sulphuric acid . . .	0.7
Potash . . .	4.9	Silica . . .	0.2
Lime . . .	0.3		

NOTE XVI. (p. 270).

AMOUNTS OF POTASH AND PHOSPHORIC ACID REMOVED BY THE FOLLOWING ROTATIONS FROM A PRUSSIAN MORGEN (.631 ACRE).

	Potash. lb.	Phosphoric acid. lb.
1. Wheat	16.40	10.67
Oats	10.47	4.59
Potatoes	66.41	18.33
Hay	39.54	11.32
	<hr/> 132.82	<hr/> 44.91

The ratio of potash to phosphoric acid is 2.96 to 1.

2. Wheat	16.90	10.67
Barley	17.44	10.65
Potatoes	66.41	18.33
Hay	39.54	11.32
	<hr/> 140.29	<hr/> 50.97

The ratio of potash to phosphoric acid is 2.76 to 1.

	Potash. lb.	Phosphoric acid. lb.
3. Rye	20.03	12.15
Oats	10.97	4.59
Potatoes	66.41	18.33
Hay	39.54	11.32
	<hr/> 136.95	<hr/> 46.39

The ratio of potash to phosphoric acid is 2.95 to 1.

4. Wheat	16.90	10.67
Oats	10.97	4.59
Mangels.	148.54	25.62
Hay	39.54	11.32
	<hr/> 215.95	<hr/> 52.20

The ratio of potash to phosphoric acid is 4.13 to 1.

5. Rye	20.03	12.15
Barley	17.44	10.65
Mangels.	148.54	25.62
Hay	39.54	11.32
	<hr/> 225.55	<hr/> 59.74

The ratio of potash to phosphoric acid is 3.78 to 1.

NOTE XVII. (pp. 253, 254).

COMPOSITION OF FARMYARD MANURE (FRESH),
(calculated by SIR JOHN LAWES).

	Total dry matter.	Total mineral matter.	Phosphoric acid calculated as phosphate of lime.	Potash.	Nitrogen.
Per cent	30.0	2.77	.50	.53	.64
Per ton (in lb.)	67.2	62.0	11.1	12.0	14.3

NOTE XVIII. (p. 232).

THE URINE.

An important consideration we have omitted to take note of in the text is the quantity of the urine voided. It is this consideration that renders the urine so much more

valuable than the solid excreta. In the case of a man it has been estimated that the urine voided is fifteen times as much, is twelve times as rich in nitrogen, three times in potash, and two in phosphoric acid, as the solid excreta (Munro). The relation of solid matter in the case of the farm animals is not exactly similar. The urine of the ox is about twice the weight of its solid excreta. Both the horse and the sheep, however, void as a rule more solid excreta than urine. Munro, in his work on 'Soils and Manures,' contrasts the composition of the urine and solid excreta of the different farm animals by the following statement:—

	1 ton of urine contains in lb. :		1 ton of solid excreta contains in lb. :
	Nitrogen.	Potash.	Nitrogen.
Cow . . .	30	20	9
Horse . . .	36	22	12
Sheep . . .	38	30	16

CHAPTER VIII.

GUANO.

Importance in Agriculture.

IN the consideration of *artificial* manures, guano deserves the first place. This it does mainly on historical grounds, as it is now largely a manure of the past. Not merely has it been used in agriculture to an extent to which no other artificial manure has as yet ever approximated, but its influence on agricultural practice has been enormous. Introduced into this country about the middle of the present century, it was the first of artificial manures to be used in large quantities.¹ It may be thus described as having introduced the modern system of *intensive* cultivation, and given rise to the now almost universal practice of artificial manuring.

¹ Bones, it is true, were in use long before guano ; but popular as they deservedly were, they had not been used, at the time of the importation of guano, to any very considerable extent.

Influence on British Farming.

It is, indeed, difficult to over-estimate the important influence which the introduction of this most valuable fertiliser has exercised on British as well as, to a large extent, on European husbandry. Before its introduction the farmer was almost completely dependent on his farmyard manure. He was tied down to a great extent, by the exigencies of the then prevailing agricultural customs, to certain rotations of crops. He could do little in the way of enriching barren soils or of ensuring a heavy yield of crop. By the use of this very potent fertiliser, he quickly discovered that the most wonderful results ensued—results which must have seemed to him at first little short of miraculous. He found that by the application of a few hundredweights per acre, poor soils could be made to yield large returns, and that barren patches in a field could be brought up to the average of the surrounding portions by sprinkling merely a few handfuls of it; that by its means a good start could be ensured to every crop, and one slow of coming away could be hastened on. In short, in this wonderful brown powder, with such a characteristic odour, the astonished farmer discovered a manure which, for the speed of its action, and for the increase of crop it gave, completely threw into the shade both farmyard manure and bones. What wonder, then, that its fame as a manure should have become so quickly known and its use

so extensive ! It thus gave a most powerful impetus to intelligent farming by bringing home to the minds of those who used it the important position nitrogen and phosphates occupied as constituents of the soil, and the influence they exercised on plant-growth. It furnished, in fact, on an enormously large scale, a practical demonstration of the principles of manuring. The educational value which the use of guano thus exercised may be said to have been very great. It also led the way to the use of the various artificial manures so much used during the last fifty years. Impressed by the value of guano, farmers were favourably disposed towards the use of other fertilisers ; and, largely owing to its widespread popularity, the new practice speedily gained ground.

Influence not wholly for Good.

But its influence, it must be admitted, was not wholly for good. In its very popularity lay the danger of its abuse. Had its value and the method of its action been more widely understood, and had the principles upon which the practice of artificial manuring depends been better realised, agriculturists would have been spared much of the needless pecuniary losses they sustained by being imposed upon by unscrupulous manure-dealers. Among the farming community the word guano soon became a name to conjure with, and under this title many spurious and worthless manures were attempted to be palmed off on the un-

wary farmer. Even the genuine article, there can be little doubt, was at one time largely adulterated; and as the farmer was almost invariably content to purchase the article not on any guaranteed chemical analysis, but simply on the ground of its appearance, colour, and more especially smell, every facility was given for the successful perpetration of such fraudulent imposition. Guano, it was very soon found, varied in its composition, but this variation in quality the farmer did not recognise. In the early days of its use all guano was in his eyes of the same value. Too often, as we have just pointed out, provided it had a good colour and a strong odour, it was all right. Under such conditions, it can scarcely be wondered at that its introduction should have proved not an unmixed blessing to agriculture.

Its Value as a Manure.

Guano derives its value as a manure from the nitrogen, phosphates, and the small amount of potash it contains. This at any rate is true of the great bulk of guano which has been used in the past. There are, as we shall immediately see, certain kinds of guano, known as phosphatic guanos, which only contain phosphates. The amount of such purely phosphatic guano directly used as a manure in this country is, however, inconsiderable, and guano may truly be described as owing its value chiefly to its nitrogen. Not a little of its value and popularity as a manure may

be said to be due to the fact that it contains all of the three important manurial constituents, and that in this respect it may be regarded in a sense as a *general* manure, thus resembling most nearly, of all artificial manures, farmyard manure. Although its sources are now, to a very large extent, exhausted, and its total annual imports into this country are at present considerably less than what they were thirty or forty years ago,¹ it may be well, on account of its historical importance, to give a somewhat detailed account of its origin, occurrence, and value as a manure.

Origin and Occurrence.

Guano (which means *dung*)—or huano, as it is spelt in the Spanish language—was first used in Peru. It seems to have been used there long before that country was discovered by the Spaniards—probably as early as the twelfth century. Regarding its origin there can be little doubt. It is almost entirely derived from the excrements of sea-birds, such as pelicans, penguins, and gulls, as well as from the remains of the birds themselves, and of seals, walruses, and various other animals.² Under the influence of a tropical

¹ The total annual imports at present may be taken at under 30,000 tons, whereas in 1855 they amounted to over 200,000 tons. For statistics on this point the reader is referred to the Appendix, Note I., p. 327.

² With regard to the origin of certain guano deposits, which are of very recent date—*e.g.*, *Angamos* and *Ichaboe*—there can be no doubt whatever, because we can witness the process of formation still taking

sun, and in a region in which rain scarcely ever falls, these excrements are soon dried, and remain little changed in their composition through centuries. Many of the Peruvian deposits must be extremely old, as they are covered up with sand and other *débris*, and are of considerable depth. Especially is this the case with deposits occurring on the mainland, such as those at Pabellon de Pica, where the layer of sand or conglomerate covering up the deposit varies in depth from a few feet to over a hundred. The effect of this superficial covering has been to protect the guano, to a certain extent, from loss of nitrogen.

Although guano of the best class has been derived from the neighbourhood of Peru, deposits have also been found in many other parts of the world—viz., in North America, West Indies, Australia, Asia, Africa, and among the islands of the Pacific.¹

place. It is not so, however, with regard to older deposits, for which some have been inclined to claim mineral origin. The best proof that such deposits owe their origin mainly to bird excrements is the comparatively large quantity of *uric acid* they contain. On the other hand, the evidence in support of the belief that they are also formed from the remains of the birds themselves and other animals, is to be found in the large proportion of phosphates they contain, and the presence in the deposits of feathers and the fossilised skeletons of the animals above mentioned.

¹ A complete list of the various deposits will be found in the Appendix, Note II., p. 327. It may be noticed that nearly all the deposits lie within 10° to 20° north and south of the Equator.

Variation in the Composition of different Guanos.

The guano found in these different deposits varies very considerably in composition. This is due to the difference in the nature of the prevailing climate of the places where these deposits occur. Where the climate is dry and warm, as is the case in Chili and Peru, the excrements dry quickly and remain very little changed, as one very important condition of fermentation—viz., moisture—is absent.¹ In a damp climate, on the other hand, speedy fermentation ensues, resulting in the loss of nearly all the organic matter, including nitrogen, in such volatile forms as carbonate of ammonia, carbonic acid gas, water, &c. The soluble alkalies, the most important of which is potash, as well as the soluble phosphates, are also, under such conditions, lost to the guano by being washed out by the rain. We have thus a wide difference in the quality of the different deposits, depending on the extent to which decomposition has taken place. Guano thus ranges from the rich nitrogenous Peruvian kind, which has undergone little or no change from the time of its deposit, to the purely phosphatic kind (such as those of Malden and Baker islands), in which everything of manurial value has been lost except the insoluble phosphate of lime. Even among the nitrogenous guanos we find a considerable difference in quality, some deposits being partially impoverished

¹ See Chapter on Farmyard Manure, p. 257.

by the action of the atmospheric moisture, dew, spray, or sea-water, but still containing a considerable proportion of their nitrogen. Other deposits, again, are largely admixed with sand, which has been blown in upon them to such an extent as to make them unsaleable. We can divide guano, therefore, into two great classes—viz., *nitrogenous* and *phosphatic*.

I.—NITROGENOUS GUANOS.

(a) PERUVIAN.

By far the most valuable and abundant deposits as yet discovered have been those on the Peruvian and Chilian coasts. As already pointed out, guano seems to have been used in this country from a very early period; and so impressed were the Incas with its importance as a manure, that the penalty of death was imposed on any one guilty of killing the sea-fowl during the breeding season in the vicinity of the deposits.

The occurrence of guano in Peru seems first to have been made known in Europe in the beginning of the eighteenth century. It was not, however, till the beginning of the present century—viz., 1804—that A. Humboldt, the great German traveller, brought some of the wonderful fertiliser home with him, and that its composition was able to be investigated by chemical analysis. Shortly afterwards, its practical value was demonstrated by experiments carried out on potatoes

by General Beatson in St Helena. To Lord Derby is due the credit of having first introduced it into this country, the earliest importation into Liverpool being in 1840. Experiments were shortly afterwards instituted in different parts of the country, prominent among which were those by Sir John Lawes and Sir James Caird; and so striking were the results obtained, that the manure rapidly found favour with the farming community—so much so, that ten years later the importations into this country amounted to no less than 200,000 tons, while in 1855 the total exports from the west coast of South America reached the enormous amount of 400,000 tons. In all, it has been estimated that since the year 1840 over 5,000,000 tons of Peruvian guano have been imported into this country.

Different Deposits.

Peruvian guano has been derived from various deposits occurring in different parts of the coast, and from a number of small adjacent islands. The richest of these was that found on Angamos, a rocky promontory on the coast of Bolivia. Samples of this guano contained as high as 20 per cent of nitrogen (equal to 24 per cent ammonia).¹ Unfortunately, however, the quantity of this deposit was extremely limited, and became rapidly exhausted. Next to this de-

¹ According to Nesbit, some of the cargoes of this guano contained hard saline lumps of very little manurial value—over 50 per cent being common salt.

posit in quality was the guano found on the Chincha islands, three little islands off the coast of Peru. These deposits were the largest which have ever been discovered, and for a period of nearly thirty years were almost the sole source of the Peruvian guano sold in commerce, over 10,000,000 tons having been exported from them alone. Some of this guano contained 14 per cent of nitrogen (equal to 17 per cent ammonia); and although part of the guano shipped from these islands was not quite so rich, yet it was all of a high-class order. The deposits on these islands were in many cases 100 to 200 feet in depth, and rested on rocks of granite. The lower layers were consequently found to be poorer in quality, and mixed with pieces of granite. The Chincha island deposits have been long exhausted,¹ and the chief deposits of Peruvian guano since worked have been those on Guanape and Macabi islands—a considerably inferior guano, containing only 9 to 11 per cent of nitrogen (equal to 11 to 13 per cent of ammonia)—which in their turn have become exhausted; from Ballestas, almost as rich as the Chincha island guano, also now exhausted; and from Pabellon de Pica, Punta de Lobos, Huanillos, Independence Bay, and Lobos de Afuera. Quite recently a deposit of very high-class guano was discovered in Corcovado, and a good many cargoes have already been shipped to this country. It is found to contain

¹ The salt exports were made in 1868.

nitrogen equal to from 10 to 13 per cent ammonia, 30 to 35 per cent phosphates, and some potash, being thus a most valuable guano. .

Appearance, Colour, and Nature.

In colour it varies from a very light to a very dark brown, the richer samples being generally lighter. Samples taken from even the same deposit have been found to differ very considerably in appearance, those taken from the lower and older layers being usually darker than those taken from the more recent upper layers. It was soon found also to vary very much in composition. After a deposit had been worked for some time, the quality of guano it yielded was found to be inferior and coarser, and in many cases mixed with pebbles or pieces of granite, porphyry, &c. This led to the custom of screening it on arrival in this country, before it was used as a manure. In the richer qualities—*e.g.*, in the Chinchá guano—little round concretionary nodules, varying in colour from pure white to dark brown, were occasionally found. Analysis showed these nodules¹ to be composed chiefly of potash salts. Sometimes, also, little crystals of almost pure ammonia salts were found. It soon became customary, therefore, to prepare guano for the market by separating the stones and reducing the whole to a fine uniform powder. One of its most characteristic

¹ For analyses of these nodules and crystals, see Appendix, Note III., p. 328.

properties, and the one which seems to have impressed the public most, was its pungent odour. Undue importance was attached to this property, in the belief that it was caused by the ammonia it contained. It may be doubted, however, whether the characteristic smell of guano is due so much to its ammonia as to certain fatty acids.

Composition.

In composition it is of a most complex nature. It contains its nitrogen in a great variety of forms, the chief of these being urate, oxalate, ulmate, humate, sulphate, phosphate, carbonate, and muriate of ammonia; and also in a rare form of organic nitrogen peculiar to guano, called guanine. According to Boussingault, some guanos contain small quantities of nitrates. Its phosphoric acid is present both in the soluble state—viz., as phosphates of the alkalies (ammonia and potash)—and in the insoluble state as phosphate of lime; and lastly, its potash is present as sulphate and phosphate. The proportion in which these different forms of nitrogen and phosphoric acid are present varies considerably in different samples. The richer a sample, as a rule, the more nitrogen in the form of uric acid it contains. The most of the nitrogen is present as uric acid and ammonia. Damp guanos contain more of their nitrogen as ammonia than dry ones, this being due to the fermentation which goes on in the former. On an average, about

a third of its total nitrogen is soluble in water. Of its phosphates, on the other hand, only about a fourth are soluble in water.

The following analyses of a sample of Chinchá island guano by Karmrodt¹ will illustrate this. (Sample dried at 212° Fahr.):—

1. *Constituents easily soluble in Water.*

Urate of ammonium	12.74
Oxalate of ammonium	13.60
Nitrogenous and sulphurous organic substances	3.61
Ammonium-magnesium phosphate	4.00
Ammonium phosphate . . . . .	.90
Ammonium sulphate	1.82
Ammonium chloride	1.55
Potassium sulphate	3.30
Sodium chloride	2.44
	<hr/>
	43.96
	<hr/>

2. *Difficultly soluble in Water, soluble in Acids,
Alcohol, and Ether.*

Uric acid	21.14
Resin	1.11
Fatty acids	1.60
Nitrogenous and sulphurous organic substances	2.29
Calcium phosphate	18.22
Phosphate of iron	1.04
Silica . . . . .	.64
	<hr/>
	46.04
	<hr/>

In the above analysis it will be noticed that none of the ammonia is present as carbonate. In most samples, however, of Peruvian guano, the ammonia in

¹ See Heiden, vol. ii. p. 356.

this form amounted to from 1 to 2 per cent. In the inferior qualities, chiefly those which had been subjected to the action of water, and consequently of fermentation, to a certain extent, this form of ammonia was found to be most abundant. Such guanos were most liable to loss of nitrogen by volatilisation.

The older Peruvian guano contained as high as 14 per cent of nitrogen (equal to 17 per cent of ammonia), and of phosphoric acid 12 to 14 per cent (equal to 26 to 28 per cent of phosphate of lime). It, however, gradually deteriorated in quality as the deposits became worked out, the percentage of nitrogen becoming year by year less, until latterly Peruvian guano, as imported, contains only from 3 to 4 per cent of nitrogen (equal to 4 to 5 per cent of ammonia). This guano is, however, richer in phosphates, containing often 50 to 60 per cent of phosphate of lime, and 3 to 4 per cent of potash.¹

(b) OTHER NITROGENOUS GUANOS.

The guanos, other than those which come from Peru, are chiefly purely phosphatic guanos, so that the term Peruvian has not unfrequently in the past been used as a generic term synonymous with the term nitrogenous, and consequently applied to all nitrogenous guanos independent of their source. There are, however, a few deposits other than the

¹ See Appendix, Note IV., p. 329.

Peruvian which have yielded considerable quantities of valuable nitrogenous guano. Of those, the richest in quality—in fact, the richest of any deposits hitherto discovered—was the Angamos guano, which came from a rocky promontory on the coast of Bolivia. The few samples of this which have been analysed showed over 20 per cent of nitrogen. Unfortunately, the deposit proved to be comparatively insignificant in amount, and has long been exhausted.

Poorer in quality, but more abundant in quantity, were the deposits found on the Ichaboe and other islands off the south-west coast of Africa. These deposits were discovered shortly after the introduction of Peruvian guano, and for a few years supplied considerable quantities of valuable manure. The deposits first discovered were soon exhausted, so that for a number of years Ichaboe guano ceased to be procurable. Fresh deposits, however, were subsequently found, and considerable quantities have of late years been used in agriculture.¹ Ichaboe guano is inferior in value to Peruvian. It exemplifies the influence of small quantities of rain on guano deposits in impoverishing them in their nitrogen. In much of the Ichaboe guano imported into this country a large amount of feathers is found. It also contains an abnormally large quantity of insoluble matter.

Among the other nitrogenous guanoses may be men-

¹ The Ichaboe guano at present exported is a fresh deposit, and is annually collected for shipment.

tioned the Patagonian, Falkland, and Saldanha Bay. They are, like the Ichaboe, of comparatively recent origin, and are collected in small quantities after the breeding season every year.

II.—PHOSPHATIC GUANOS.

Phosphatic guanos, as already pointed out, are similar in origin to nitrogenous guanos. In their case, however, the nitrogen, alkalies, and soluble phosphates which they originally contained have been almost entirely lost by the decomposition of their organic matter and the action of water.¹ Most of them still contain very small quantities of nitrogen, amounting to a fraction of a per cent. Of these deposits there are very many occurring on islands in different parts of the world. In appearance the guano obtained from them is very different from nitrogenous guano, being much lighter in colour, and of a fine powdery nature. It forms a very rich phosphatic guano, containing in many cases between 70 and 80 per cent of insoluble phosphate of lime. Such guanos are largely used in the manufacture of high-class superphosphates, by treating them with sulphuric

¹ Further chemical changes have occurred in certain cases between the guano and the limestone rock beneath, resulting in the formation of what is called a "crust" guano. Such guanos form a soft phosphatic rock, and are extremely rich in phosphates. As examples of these "crust" guanos may be mentioned Sombrero, Curaçao, Aruba, Mexico, and Navassa phosphates.

acid. Being of an insoluble nature, they are not very suitable for direct application to the soil. Of these phosphatic guanos the following are the chief—those marked in italics being still unexhausted:—

1. *Baker*, *Jarvis*, *Howland*, *Starbuck*, *Flint*, *Enderbury*, *Malden*, *Lacepede*, *Browse*, *Huon*, *Chesterfield*, *Sydney*, *Phoenix*, *Arbrohlos*, *Shark's Bay*, and *Timor*—all found on islands in the Pacific Ocean.

2. *Mejillones*, on the coast of Bolivia.

3. *Aves*, *Tortola*, *Mona*, and other deposits in the West Indies.

4. *Kuria Muria* islands, in the Arabian Gulf.

For further particulars as to the composition of these different guanos, the reader is referred to the Appendix, Note V., p. 329.

Inequality in Composition.

That guano was a substance of by no means uniform composition was a fact early recognised in the history of the trade. Not only did guano from different deposits show on analysis different percentages of the manurial ingredients, but different samples of guano from the same deposit were often found to differ very considerably from one another. It soon became the custom, therefore, to sell it on chemical analysis, each separate cargo being carefully analysed. But this custom did not wholly obviate the difficulty, as the guano in even one cargo might differ. In the case of the older and richer guanos, there was certainly more

uniformity in quality, but they were liable to differ in their percentage of nitrogen.¹ As, however, the deposits became gradually worked out, their lower layers were found more or less largely admixed with stony and earthy matter, and their composition was naturally rendered very variable. This state of matters was unsatisfactory to buyers and sellers, and led to much friction between the two, as it was found wellnigh impossible on the part of the seller to guarantee the composition of his manure. The custom of preparing the material by reducing it to a fine powder before sending it into the market, and the custom, subsequently introduced, of treating it with sulphuric acid, have done away with this difficulty to a large extent.

“Dissolved” Guano.

The treatment of guano with sulphuric acid was first had recourse to in the case of cargoes damaged with water. In such guano, as has been already pointed out, fermentation has been permitted to take place, with the result of the formation of volatile carbonate of ammonia in greater or less quantity. By the addition of sulphuric acid the ammonia was fixed, and the guano was prevented from losing its most valuable constituent. It was soon found, however, that guano so treated possessed greater activity as a manure. The result of the sulphuric acid was to

¹ The presence in the old Peruvian guano of concretionary nodules has already been referred to.

increase very materially the amount of its soluble phosphates, and also its soluble nitrogen compounds.¹ It had, moreover, the effect of producing a guano of uniform composition. The custom, first introduced in 1864 by Messrs Ohlendorff & Co., was soon largely practised. The guano is treated with 25 to 30 per cent sulphuric acid (sp. gr. 1.73). After a short time the resulting hard mass is, by means of disintegrators, reduced to a uniform powder.

“Equalised” or “Rectified” Guano.

As guano decreased in its quality the demand for a high-class article became more and more difficult to meet. This led to the custom of “fortifying” or “rectifying”—as it is variously called—the natural material with sulphate of ammonia. A manure closely resembling in the percentage of its manurial constituents the older rich guanos is thus obtained. Of these so-called “equalised” guanos, two qualities are at present sold, the first being guaranteed to contain nitrogen equal to 8 to 9 per cent ammonia, 30 to 35 per cent phosphates, and 2 to 3 per cent of potash; the second quality containing only about half as much nitrogen, but more phosphates.

However valuable this fortified guano may be—and it is, undoubtedly, a most valuable manure—its action cannot be supposed to be exactly similar to the old

¹ According to Vogel the nitrogen as urates is converted by the sulphuric acid into ammonia salts.

Peruvian guano, which it resembles in the percentage of its nitrogen, phosphates, and potash. Much of the distinctive value of guano as a manure, as will be pointed out immediately, lies in the fact that it contains its manurial ingredients in a variety of differently soluble compounds, which are gradually rendered available in the soil for the plant's needs. This undoubtedly is one of the reasons why the action of guano among manures is quite unique; and there are other reasons which we probably do not clearly understand. However skilfully the composition of the guano may be artificially simulated, it still remains an undoubted fact that the "equalised" guano is not exactly similar in its action to the genuine article. Nevertheless, that it is superior in its results to the poorer classes of guano at present available, and to ordinary compound manures, there can be little doubt. A great merit of the equalised guano is, however, that it is sold at a lower price than guano as imported; and as the guano is sold on a guaranteed analysis, the practice has done much to advance the true interests of agriculture.

Its Action as a Manure.

Next to farmyard manure, guano may be regarded as the most "general" of all the commonly used manures; for in addition to nitrogen, phosphoric acid, and potash, it contains nearly all the other plant ingredients, such as lime, magnesia, &c. Its special value as a manure, however, does not merely consist

in the amount of valuable plant-food it contains. Like farmyard manure, it owes much of its characteristic action to the state of the intimate mixture of its manurial constituents, and also, as has already been pointed out, to the fact that it contains those constituents in a great variety of chemical forms, each of which differs in its solubility, and consequently availability for the plant's needs. Take, for example, the great number of different forms of nitrogen it contains. Some are in the condition in which plants can immediately absorb them, while the rest are in a series of less and less available forms, which, however, are gradually converted into available forms as the plant requires them. Like farmyard manure, again, it may be applied with almost equally good results to all kinds of crops and on all kinds of soils. We have in guano, in short, an admirable example of the value of applying our manurial ingredients in different forms. That this is no mere theory is abundantly proved by the large number of different experiments which have in the past been carried out with guano, more especially the well-known experiments made by Grouven, the German chemist. In those well-known experiments, guano was tested against a large variety of different fertilisers, and the tests were so arranged that in most cases the amounts of nitrogen, phosphoric acid, and potash were the same in the other manures used. In short, these experiments prove in a very striking manner that a manure artificially made up out

of most valuable fertilisers, such as nitrate of soda, sulphate of ammonia, superphosphate, &c., so as to closely resemble in its composition guano, is by no means similar in its effects to the genuine article. As in farmyard manure, so in guano: we must look to the complexity of the composition of both these fertilisers in order to fully estimate their worth. There is in the action of both manures much that we cannot explain, or even, as yet, understand. The action of guano is merely one of many problems in the science of manuring which illustrate how unsatisfactory, despite the great amount of research already carried out, is our knowledge of this most important department of agriculture.¹

Proportion of fertilising Constituents in Guano.

Guano must be regarded as a nitrogenous and phosphatic manure, as the quantity of potash it generally contains is small. In many soils, more especially in such a country as Scotland, this deficiency in potash is not of so much importance, as the value of potash as an artificial manure is less than is the case with the other two ingredients. In soils, however, lacking potash, guano ought to be supplemented with some potash manure. With regard to the nitrogen and phosphoric acid, we may ask if these two constituents are in the best proportions. This question does not admit of a direct answer. In the first place, the pro-

¹ See Appendix, Note VI. p. 330.

portion in which these two ingredients are present is variable. In the old rich Peruvian guanos, as we have above shown, the nitrogen was more abundant than is the case at present. Such guanos, it was found, were best supplemented with phosphatic manure when applied to the field. In the "equalised" and "dissolved" guanos, which are now so largely sold, manufacturers attempt to adjust the percentage of nitrogen and phosphoric acid to what is considered the best proportion in most cases. As, however, we have again and again to point out, regard must be had both to the soil and the crop in determining what is the best proportion of the manurial ingredients in a manure. For cereals it may be well supplemented by nitrogenous manures, while for roots it may be well supplemented by phosphatic manures.

Mode of Application.

Like all manures, it is desirable to apply it in as fine a condition as possible, so as to ensure as thorough a mixture with the soil-particles as practicable. In order, furthermore, to prevent any risk of loss through volatilisation of the ammonia, as well as to ensure even distribution, it is best applied mixed with dry earth, ashes, sand, or some other substance,—not lime, however. The custom of applying along with the guano common salt, has been proved by numerous experiments to be highly beneficial to the action of the guano as a manure. The exact nature

of the action of salt as an adjunct to manures is a point which has elicited much discussion. Its action is probably to be ascribed to a number of causes. For one thing, it probably acts as an antiseptic in retarding the fermentative action which has a tendency to go on so rapidly in such manures as guano. It further increases the power of the manure to attract moisture from the air—a most important property in the case of drought. Some experiments by Dr Voelcker illustrate this in a striking manner. Two lots of guano—one pure and one mixed with salt—were exposed to the action of the air for a month, and were then tested as to the amount of water they contained, when it was found that the lot containing the salt had absorbed 2 per cent more water than the other.

Much stress has been laid on the importance of having the guano buried a certain depth in the soil; and many experiments have been carried out to prove how much better it acts when so applied. This is probably due to the prevention of any loss of volatile ammonia, and the mixture of the manure with the soil-particles before it comes in contact with the plant-roots. This last precaution is an important one, for it has been found that the raw material is apt to have a bad effect on the seed or the plant's roots. This has been found to be especially the case in regard to potatoes, the quality of which has been found to suffer when the guano is brought

into direct contact with the tubers. As guano is a manure which is speedily available, it is desirable to apply it as shortly before it is required by the plant as possible. It is therefore generally best applied in spring, shortly before seed-time, or indeed at the same time. Where farmyard manure is used, the guano has been recommended to be used as a top-dressing in small quantities. In the majority of cases it will be advisable, however, not to apply it as a top-dressing, for the various reasons above-mentioned.

Quantity to be used.

As to the quantity to be used, this of course will depend on the soil, the crop, and the amount and nature of the other manures employed: 1 to 4 cwt. per acre have been the usual limits, but even heavier dressings have been commonly resorted to, especially in Scotland, where 6 to 8 or even 9 cwt. for turnips are often used. Sir J. B. Lawes and Sir James Caird long ago, shortly after the introduction of guano, estimated, from the experiments they carried out, that the application of 2 cwt. per acre to the wheat crop gave an increase of 8 to 9 bushels in grain, and added a fourth to the quantity of straw. The former authority recommends 2 to 3 cwt. per acre for wheat, to be sown broadcast and harrowed into the land before sowing the seed. We have already stated that it may be used in all soils and for all kinds of

crops. While this is so, it has been found to have specially favourable results when applied to the turnip crop, when it may be used in larger quantities than in the case of cereals. When applied to the turnip crop, it is well to use the more phosphatic guanos or to supplement it with superphosphates. By applying it in two lots, the larger portion before seed-time and the rest between the drills after the turnips are up, excellent results have been obtained. It has also proved an admirable manure for mangels. On the whole, it gives best results on heavy soils and in a dampish climate.

Adulteration of Guano.

Probably no artificial manure has been subjected to greater adulteration in the past than guano. This has been due to the fact that the practice of selling guano on analysis—especially among retail buyers—did not largely obtain in the early years of the trade. A good deal of this adulteration was probably caused by ignorant prejudice on the part of the farmer, to whom the pungency of its smell and its colour were too apt to be ranked as its most important properties. The variation in the quality of different kinds of guano was too often not sufficiently realised by the buyer, who not unfrequently was made to pay as high a price for guano of an inferior quality as he ought to have paid for that of the best quality. Indeed no manure illustrates the importance of chem-

ical analysis more than guano. Among the different forms of adulteration practised may be mentioned the addition of such substances as sawdust, rice-meal, chalk, sulphates of lime and magnesia, common salt, sand, earth, peat, ashes of various kinds, and water. There can be no doubt, however, that such adulteration has now long ceased to be practised to any extent. Nevertheless, it may be of use to draw attention to one or two of the tests by means of which some of the commoner forms of adulteration may be detected. One or two are extremely easily detected—as, for example, adulteration with sand or other mineral substances. In such a case, the percentage of ash left on burning a small portion of the guano will be found to be excessive. The percentage of ash in a sample of genuine Peruvian guano should not exceed from 50 to 60 per cent. The colour of the ash is another important point, and may serve as a further indication of adulteration. In the case of genuine guano, this should be whitish or greyish. Red-coloured ash generally points to the adulteration of the guano with some mineral substance containing iron—such, *e.g.*, as Redonda phosphate, a mineral phosphate of iron and alumina. Where the ash is white, but excessive in quantity, adulteration with common salt, sulphate of magnesia, gypsum, or chalk, may be suspected. The last-named substance is easily detected by treating it with any of the common acids, when brisk effervescence, due

to the liberation of the carbonic acid, will ensue.¹ A further point of importance with regard to the ash is its solubility in water and in acids. A large insoluble residue may be taken as indicating adulteration with sand. Adulteration with water is also easily detected by heating a sample to the boiling temperature and determining the loss it sustains. Of course the amount of water varies in different samples. The appearance of the guano will serve fairly well to detect whether it is abnormally moist. It may be added, in conclusion, that Peruvian guano is extremely light; and while this by itself is not a sufficient test of genuineness, it may serve to confirm other tests.

III.—SO-CALLED GUANOS.

Before concluding this chapter, reference may be made to certain manures which are commonly known under the name of guanos—such as “fish-guano,” “flesh-guano,” “meat-meal-guano,” and “bat-guano,”—as well as to manures which may more conveniently be described here—viz., “fowl and pigeon dung.”

Fish-Guano.

The application of fish, not suited for other pur-

¹ It must be remembered, however, that even genuine guano contains a certain quantity of carbonate of lime, and will give a slight amount of effervescence when so treated.

poses, to the fields as a manure is a practice which has obtained in certain parts of the country for a number of years. In many districts on the sea-coast, where fishing is the chief industry, the only way in the past of disposing of a superabundant catch of herrings, for example, has been to utilise them as a manure. From such a practice has sprung up what is now an important and ever-increasing trade—viz., the manufacture of fish-guano.

This manufacture was first started, and is still most largely practised, in Norway. The guano obtained varies very considerably in quality according to the nature of the process employed, and as to whether the guano is made from whole fish or merely from fish-offal. The latter source is the common one. The manufacture is carried on at the fish-curing stations, and the quality of the guano made from this source is somewhat different from that made from whole fish, as a large proportion of the fish-offal is made up of bones and heads. Large quantities of Norwegian fish-guano are exported to various parts of Europe.

The best quality of this guano may contain as much as 10 per cent of nitrogen, but as a rule it is nearer 8 per cent. A very considerable variation in the amount of phosphoric acid occurs for the reason above stated, the guano made from fish-scrap being naturally much richer in this ingredient than whole-fish guano. The phosphoric acid may be said to range from 4 to

15 per cent, and there is also a small quantity of potash present.

Guano is also manufactured in Norway from the carcasses of whales. Such guano contains from $7\frac{1}{2}$ to $8\frac{1}{2}$ per cent of nitrogen, and about $13\frac{1}{2}$ per cent of phosphoric acid.

In America fish-guano is manufactured to a considerable extent—one important source being the menhaddo, a coarse sort of herring. This fish is caught for the sake of its oil, which is extracted by boiling, the residue being manufactured, after pressing and drying, into guano.

In this country the manufacture of fish-guano is carried out to a considerable and increasing extent. Formerly it was imported from Norway to a larger extent than is now the case, the present annual imports amounting only to 1000 or 2000 tons. The total annual production in the United Kingdom is probably 7000 or 8000 tons.

Value of "Fish-Guano."

That fish-guano is a valuable manure there can be no doubt. What, however, impairs its value is the fact that, as a rule, it contains a certain amount of oil. The effect of this oil is to retard fermentation and decomposition when the guano is applied to the soil, and thus render its action slower than would otherwise be the case.

When applied to the soil, therefore, every oppor-

tunity ought to be given to promote its fermentation. It is best applied some time before it is likely to be used. It ought to be well mixed with the soil-particles, and not allowed to lie on the top of the soil. Its best effect will be on light well-cultivated soils, which permit of the access both of sufficient moisture and of sufficient air for rapid fermentation. Its value as a manure for hops, vines, grass, and strawberries has been found to be considerable. It has been recommended to be applied along with farmyard manure; and such a mode of application is no doubt well suited to promote its decomposition. It has also been used for mixing with superphosphate of lime. Professor Storer has advocated a more general use of fish as a manure than is at present the case. He suggests that even fish not suitable for edible purposes might be caught for the purpose of conversion into manure. The difficulty of preserving fish, however, is considerable; and he suggests the use of potash salts, such as muriate of potash, or lime for this purpose. The benefit of using potash would be twofold. In addition to acting as a preservative, it would considerably enhance the value of the resulting guano as a manure. There is much truth in Professor Storer's views; and no doubt, as our sources of artificial nitrogenous manures grow more limited, the manufacture of fish-guano will be carried on in the future on a larger and more systematic scale than hitherto.

Meat-meal Guano.

What is called "meat-meal guano" is generally that made from the refuse of the carcasses of cattle after they have been treated for their meat-extract according to Liebig's process. The meat-meal is used both for feeding and manurial purposes. Considerable quantities¹ of this guano are imported annually into this country from South America, Queensland, and New Zealand,—that coming from Frey Bentos, in Uruguay, being best known. It is a valuable manure, especially so for its nitrogen, which varies from 4 to 8 per cent, while it contains of phosphoric acid from 13 to 20 per cent. Some meat-meal guanos contain as much nitrogen as 11 per cent.

In some parts of the world, more especially in Germany, the carcasses of horses, as well as cattle, dogs, pigs, &c., which have died of disease, are converted into a guano. They are subjected to treatment by steam in digestors, by which means the fat and gelatine are separated and utilised, while the remaining portion of the animal is converted into guano. Other processes are also employed. The resulting manure contains from 6 to 10 per cent of nitrogen, and from 6 to 14 per cent of phosphoric acid.

Value of Meat-meal Guano.

Meat-meal guano is a valuable nitrogenous manure.

¹ The annual imports may be stated at from 3000 to 4000 tons.

The same remarks apply to it as to fish-guano, although it ferments probably very much more quickly than the latter, and is undoubtedly a more valuable manure.

Bat Guano.

In conclusion, we may consider bat guano. Bat guano, which is really a very rare curiosity, has been found accumulated in hot climates in caves.

The samples which have been analysed have differed very much in quality, some containing as much as 9 per cent of nitrogen and 25 per cent of phosphoric acid. Provided it could be obtained in any quantity, and of a quality even approximating to the above analysis, it need scarcely be pointed out that bat guano would be a most valuable manure.

A singular point about its composition is, that it has been found to contain a considerable proportion of its nitrogen (as much as 3 per cent) in the form of nitrates.

Pigeon and Fowl Dung.

Pigeon dung is a manure which historically is of great importance. The dung of pigeons was used as a manure by the ancient Romans; and even in modern times, more especially in France, it was considered a most important fertiliser. Despite these facts, pigeon dung is by no means a rich manure, and its composition compares most unfavourably with that of the guanos we have just been considering. According to

Storer,¹ it only contains from $1\frac{1}{4}$ to $2\frac{1}{2}$ per cent of nitrogen, and from $1\frac{1}{2}$ to 2 per cent of phosphoric acid, and a little over 1 per cent of potash.

The dung of poultry is just about as poor, fowl dung containing from .8 to 2 per cent of nitrogen, $1\frac{1}{2}$ to 2 per cent of phosphoric acid, and a little under 1 per cent of potash; while that of ducks and geese is even poorer.²

From these statements it will be seen that the excrements of pigeons, hens, and ducks do not form a rich manure. One thing about pigeon dung which is to be noticed, is the fact that it ferments very quickly.

None of the pseudo-guanos, however rich they may be in manurial ingredients, can be regarded as equal in their action to the genuine article, for reasons which we have gone into already when considering the action of guano.

¹ Agricultural Chemistry, vol. i. p. 367.

² See Appendix, Note VII., p. 331.

APPENDIX TO CHAPTER VIII.

NOTE I. (p. 297).

PERUVIAN GUANO IMPORTED INTO THE UNITED KINGDOM,
1865-1893.

Year.	Tons.	Year.	Tons.
1865 . . .	213,024	1881 . . .	33,393
1870 . . .	247,028	1882 . . .	27,382
1871 . . .	144,735	1883 . . .	36,713
1872 . . .	74,964	1884 . . .	15,802
1873 . . .	135,895	1885 . . .	...
1874 . . .	94,346	1886 . . .	28,733
1875 . . .	86,042	1887 . . .	5,784
1876 . . .	158,674	1888 . . .	16,446
1877 . . .	111,835	1889 . . .	17,000
1878 . . .	127,813	1890 . . .	19,000
1879 . . .	45,475	1891 . . .	11,000
1880 . . .	58,631	1892 . . .	14,000

NOTE II. (p. 298).

GUANO DEPOSITS OF THE WORLD.

SOUTH AMERICA—

Peru.—In various islands off the coast—viz., Chincha, Guanape, Ballestas, Macabi, Lobos, and Patillos; and on different parts of the coast—viz., Pabellon de Pica, Chipana, Huanillos, Punta de Patillos, Independence Bay, and Lobos de Afuera.

Columbia.—In different parts of the States of Venezuela, New Granada, and Ecuador. Guano coming from these parts is often known as Columbian guano, or according to the name of the State in which it is found. Maracaibo and Monks guanós come from the coast of Venezuela. Deposits are also found on the Galapagos Islands, to the west of Ecuador.

Bolivia.—Mejillones, Patagonia, Leon's.

NORTH AMERICA—Deposits have been found on the coasts of Mexico and California ; on the Raza and Patos Islands ; and on the coasts of Labrador. They have also been found on the Islands of Curaçao, Aruba, and Navassa in the Gulf of Mexico.

AFRICA—On the west coast deposits have been found at Algoa Bay, Saldanha Bay, and on the Island of Ichaboe.

AUSTRALIA—Shark's Bay and Swan Island.

WEST INDIES—Sombbrero, Aves, and Cuba.

PACIFIC OCEAN—On the Islands of Baker, Jarvis, Howland, Malden, Starbuck, Fanning, Enderbury, Lacepede, Browse, Huon, and Surprise.

ASIA—Deposits at Kuria Muria on the Arabian coast, and on the Sandwich Islands. (See Heiden's 'Düngerlehre,' vol. ii. p. 349.)

NOTE III. (p. 303).

COMPOSITION OF CONCRETIONARY NODULES.

(Analyses by Karmrodt.)

No. 1.			
Potassium sulphate	.	.	7.49
" phosphate	.	.	9.52
Sodium "	.	.	9.08
Ammonium "	.	.	7.57
Calcium sulphate	.	.	3.40
Ammonium urate	.	.	4.09
" oxalate	.	.	41.28
Nitrogenous organic matter	.	.	10.17
Water	.	.	7.40
			<hr/>
			100.00

Nitrogen . . . 14.84

No. 2.			
Potassium sulphate	.	.	45.64
Sodium "	.	.	13.22
Ammonium "	.	.	10.23
" oxalate	.	.	9.14
Basic ammonium phosphate	.	.	12.09
Precipitated ammonium phosphate	.	.	4.78
Organic matter	.	.	.94
Insoluble	.	.	1.90
Water	.	.	2.06
			<hr/>
			100.00

NOTE IV. (p. 306).

The following analyses, being the average of a large number of different samples analysed from time to time in the chemical laboratory of the Pommritz Agricultural Experimental Station, show the gradual deterioration of Peruvian guano, as regards its percentage of nitrogen, during the years 1867-81:—

Nitrogen.			Nitrogen.		
1867 . . .	13.16		1873 . . .	9.16	
1868 . . .	11.98		1874 . . .	9.83	
1869 . . .	13.66		1878 . . .	7.10	
1870 . . .	12.37		1879 . . .	6.95	
1871 . . .	10.04		1880 . . .	7.07	
1872 . . .	10.72		1881 . . .	6.93	

NOTE V. (p. 309).

COMPOSITION OF DIFFERENT GUANOS.

The following is a list of the more common nitrogenous and phosphatic guanos which have been used in the past or are at present in use. Those printed in italics are still being worked. As their value depends on their nitrogen and phosphoric acid, these alone have been given. The percentages must be taken as mere approximations, as the quality of different cargoes from the same deposits varies very much. The table may be found useful for reference.

Nitrogenous Guanos.

	Nitrogen = Ammonia.		Phosphoric acid per cent.	} = { Tricalcic phosphate. per cent.
	per cent.	per cent.		
Angamos . . .	20	24	5	11
Chincha . . .	14	17	13	28
Ballestas . . .	12	15	12	26
Egyptian . . .	11	13	19	41
Guanape . . .	11	13	...	...
Macabi . . .	11	13	12	26
Corcovado . . .	11	13	15	33
<i>Saldanha Bay</i> . . .	9	11	9	20
<i>Ichaboe</i> . . .	8	10	9	20
Independence Bay . . .	7	9	12	26

	Nitrogen per cent.	= Ammonia. per cent.	Phosphoric acid per cent.	} = { Tricalcic phosphate. per cent.
<i>Pabellon de Pica</i> .	7	9	14	31
<i>Punta de Lobos</i> .	4	5	15	33
<i>Huanillos</i> .	6	7	13	28
<i>Penguin</i> .	5	6	11	24
<i>Patagonian</i> .	4	5	18	39
<i>Falkland Islands</i> .	4	5	14	31

Phosphatic Guanos.

	Phosphoric acid per cent.	} = { Tricalcic phosphate. per cent.
<i>Maracaïbo, or Monks</i> .	42	92
<i>Raza Island</i> .	40	87
<i>Curaçao</i> .	40	87
<i>Baker Island</i> .	39	85
<i>Starbuck</i> .	38	83
<i>Enderbury</i> .	37	81
<i>Californian</i> .	35	76
<i>Aves</i> .	34	74
<i>Fanning Island</i> .	34	74
<i>Howland</i> .	34	74
<i>Sidney Island</i> .	34	74
<i>Mejillones</i> .	33	72
<i>Lacepede Island</i> .	33	72
<i>Malden Island</i> .	32	70
<i>Sombrero</i> .	32	70
<i>Browse Island</i> .	31	68
<i>Huon Island</i> .	28	61
<i>Patos Island</i> .	24	52
<i>Jarvis Island</i> .	20	44
<i>Cape Vert</i> .	11	24

NOTE VI. (p. 314).

It may be of interest to refer to a theory put forward by Liebig as to the action of oxalic acid in guano. This, he considered, had the effect of gradually rendering the insoluble calcium phosphate soluble, and giving rise to the formation of ammonium phosphate and calcium oxalate. Such an action would probably take place were the guano allowed to ferment by itself. We know, however, that when it is brought in contact with the soil-particles, all its soluble phosphate is converted into precipitated phosphate.

NOTE VII. (p. 326).

ANALYSES OF DUNG OF FOWLS, PIGEONS, DUCKS, AND GESE.

(Storer's 'Agricultural Chemistry,' vol. i. p. 367.)

	Fowls.	Pigeons.	Ducks.	Geese.
Water . . .	56.00	52.00	56.60	77.10
Organic matter . . .	25.50	31.00	26.20	13.40
Nitrogen . . .	1.60	1.75	1.00	.55
Phosphoric acid . . .	1.5—2.00	1.5—2.00	1.40	.54
Potash . . .	.80—.90	1.0—1.25	.62	.95
Lime . . .	2.00—2.50	1.5—2.00	1.70	.84
Magnesia . . .	.75	.50	.35	.20

According to a computation by a Belgian farmer, a pigeon yields about 6 lb. of dung in a year, a hen about 12 lb., a turkey or goose about 25 lb., and a duck 18 lb.

CHAPTER IX.

NITRATE OF SODA.

NITRATE of soda,¹ or, as it is more correctly designated from a chemical point of view, sodium nitrate, now forms the chief artificial nitrogenous manure in use. Along with sulphate of ammonia, it has taken the place once held in the manure markets by the older Peruvian guano, and may without doubt be reckoned, at present prices, one of the cheapest and most valuable of the artificial sources of nitrogen for the plant. It is some sixty-two years ago since it was first exported from South America into this country. The total exports in that year amounted to about 800 tons, and some indication of the enormous extent to which the use of this valuable fertiliser has been developed since then will be obtained from the statement that the total exports at present amount to little less than 1,000,000 tons per annum, representing a monetary value of 6 to 7 millions sterling. Of this

¹ This substance is also largely known under the name Chili saltpetre, to distinguish it from potassium nitrate or common saltpetre.

quantity about 120,000 tons are imported into Britain.¹ While its chief use is for manurial purposes, it must not be imagined that it is only used for this purpose. A certain amount is used in connection with various chemical manufactures—for instance, that of nitric and sulphuric acid—and also in the manufacture of saltpetre, the chief constituent of gunpowder.

Date of Discovery of Nitrate Deposits.

The exact date of the discovery of the nitrate deposits seems to be a point of considerable dubiety. The earliest published description of them was written by Bollaert about the year 1820, in which year, it is stated, the first shipment was made to England. It was not, however, till some ten or twelve years later that the Peruvian Government, to whom they then belonged,² seems to have recognised their value. The most important deposits are found in the vicinity of the town of Iquique, which is the chief nitrate port of South America. It is a somewhat striking fact that this substance, which has conclusively proved itself to be the most potent of all known artificial agents in the promotion of vegetable growth, should be found in a district utterly lacking the slightest traces of vegetation of any kind. Lest such a statement should seem

¹ See Appendix, p. 351.

² We may remind our readers that these nitrate deposits were largely the cause of the late war between Chili and Peru, which resulted in the cession to Chili by Peru of the province of Tarapaca, where the most important deposits are situated.

to savour of irony, we hasten to explain that the singular barrenness of this part of the country is largely due to the character of its climate, the deposits occurring in the midst of sandy deserts,¹ on which rain never falls.

Their Origin.

The origin of these nitrate-fields is a geological problem of very considerable interest, the difficulty of which is greatly enhanced by their altitude—3000 to 4000 feet above the sea-level—and their distance inland, which amounts in some cases to eighty or ninety miles from the sea-coast. The nitrate deposits are not the only saline deposits found in Chili. According to the late David Forbes,² they are not to be confused with other saline formations, which appear at intervals scattered over the whole of that portion of the western coast, on which no rain falls. The latter stretch from north to south for a distance of more than 550 miles—their greatest development being between latitudes 19° and 25° south. The depth to which they extend downwards varies considerably. Most of them, however, are of a very superficial character, and “they always show signs of their existence by the saline

¹ The other nitrate deposits are found in the provinces of Antofagasta and Atacama, and a certain amount of the refined article is exported from these places. The amount, however, is inconsiderable as compared with that which comes from the province of Tarapaca.

² See his elaborate article on the Geology of Bolivia and Peru, published in the ‘Quarterly Journal of the Geological Society’ for November 1860.

efflorescence seen on the surface of the ground, which often covers vast plains as a white crystalline incrustation, the dust from which, entering the nostrils and mouth of the traveller, causes much annoyance, whilst at the same time the eyes are equally suffering from the intensely brilliant reflection of the rays of a tropical sun." These saline incrustations, or *salinas*, as they are generally called, are chiefly composed of salts of lime, soda, magnesia, alumina, and of boracic acid. Their composition would lead one to attribute their origin to the evaporation of salt water; for, with the single exception of boracic acid,¹ all the mineral substances are such as would be obtained by the evaporation of sea-water, or by the mutual reactions of its salts with the constituents of the adjacent rocks. As there is "indisputable evidence of the recent elevation of the whole of this coast," volcanic upheaval might be reasonably held to explain their altitude. Their comparative proximity to the coast would seem further to favour this theory. On these grounds, therefore, Forbes is inclined to think that they owe their origin to the evaporation, under the influence of a tropical sun, of lagoons of salt water, the communication of which with the sea had been cut off by the rising of the land.

Forbes and Darwin on the Theory of their Origin.

The obvious difficulty of accounting for the formation of the larger deposits by such a theory he meets

¹ The source of the boracic acid is probably volcanic.

by saying that it is only necessary to suppose that, even after the partial isolation of the lagoons by the elevations of the coast, they might still have maintained tidal or occasional communication with the sea by means of lateral openings in the chain of hills separating them from the ocean. In such cases there would be a gradual accumulation of salts, very much greater in amount than that due simply to the evaporation of the water originally contained in the lagoons. The above theory of the origin of the lower saline deposits may go to explain the mode of formation of the nitrate-fields; but in this case several difficulties present themselves. One is the much greater altitude of the latter, as well as their greater distance inland. This difficulty, however, may be met by assuming that they are of older origin than the lower deposits, and have been subjected to a correspondingly greater amount of volcanic upheaval. There is abundance of proof that this part of the continent has been the scene in the past of such volcanic upheaval. Forbes is of opinion that there is the fullest evidence to prove that, even since the arrival of the Spaniards, a very considerable elevation of the land has taken place over the greater part, if not the whole extent, of the line of coast; while Darwin states that he has convincing proof that this part of the continent has been elevated from 400 to 1200 feet since the epoch of existing shells. Furthermore, elevations of the coast-line, amounting in many cases to several feet, are known to have hap-

opened within recent times, while earthquakes and volcanic disturbances of a less striking nature are still of common occurrence. Successive lines, indicative of old sea-beaches, can be distinctly traced stretching inland, one behind the other; and patches of sea-sand and water-worn stone, found at a great distance from the coast, both in valleys and at altitudes much greater even than 4000 feet, point to the same conclusion.¹ The difficulty, therefore, of altitude and distance from the coast cannot be regarded as insuperable.

Source of Nitric Acid.

A difficulty, however, which is not so easily met, is afforded by the presence of the nitric acid which, in combination with the soda, forms the nitrate of soda. It is scarcely necessary to inform our readers that nitrogen—except, of course, in small quantities in the free state—is not a normal constituent of salt water. The question, therefore, of greatest interest in connection with the formation of these nitrate-beds is, Whence has the nitric acid been derived? Several theories have been put forward to account for it.

Guano Theory.

One is to the effect that it owes its origin to huge

¹ A friend of the present writer, who has visited this part of the west coast of South America, informs him that at one point of the coast at Mejillones (in Bolivia) he could trace the remains of no fewer than twelve distinct sea-beaches, situated at different distances from the sea, and rising to an altitude of 2500 feet.

guano deposits, originally covering the shores of the large salt lakes which, by the subsequent overflowing of their shores, effected the mixture of the guano with the salts. In this way, by a slow process of decomposition, nitrate of soda would be ultimately formed.¹ This theory, apart from other considerations, seems at first sight extremely plausible, more especially when we remember that it is on this very coast that the greatest guano deposits have been found, and that the famous Chincha Islands, which alone have yielded over 10 million tons of this valuable fertiliser, are comparatively near the scene of the nitrate deposits. What seems further to support this theory, is the actual occurrence in the nitrate-fields themselves of small quantities of guano. But however plausible it may appear at first sight, it does not bear closer criticism. One very serious objection is the absence in these deposits of phosphate of lime, which is the largest constituent of guano. If they were really due to guano, how does it happen that the insoluble phosphate of lime should have disappeared, while the easily soluble nitrate of soda should alone be preserved? Again, assuming this theory to be correct, we should naturally expect to be still able to find evidence of the chemical changes which would under such

¹ In this change, lime derived from the sea-shells would play an important part. Modern researches have shown, as we have already said in a previous chapter, that, in the conversion of organic nitrogen into nitrates, the presence of carbonate of lime is a necessary condition.

circumstances have taken place, in the shape of portions of the guano in the transition stage. Such evidence, however, the most careful investigations have failed to detect. Apart, however, from the above objections, there seems to be little doubt, from evidence afforded by traces of birds' nests, &c., that the guano found in the nitrate-beds was deposited subsequent to the formation of the nitrate of soda.

Nitric Acid derived from Sea-weed.

The most probable theory seems to be that put forward by Nollner. The origin of the nitric acid is, according to him, to be ascribed to the decay of great masses of sea-weed, which, by means of hurricanes such as are still prevalent in these districts, were driven into the lagoons. The chief difficulty in the way of accepting this theory is the enormous quantity of sea-weed required to produce the millions of tons of nitric acid these deposits contain. It must be remembered, however, as bearing upon this point, that the occurrence of gigantic masses of sea-weed in the Pacific Ocean¹ is by no means uncommon even at the present time. If, to understand the formation of coal, we must suppose the Carboniferous period to be one during which exceptionally luxuriant growth of vegetation took place, we may be

¹ The Gulf weed is an instance in point. Huge masses of floating sea-weed are sometimes found, 500 to 600 miles in length, forming the so-called Saragossa Sea.

permitted to suppose a similar luxuriant growth of sea-weed during the formation of the nitrate deposits. Very strong confirmation of the truth of this theory is further afforded by the presence in large quantities, in the raw nitrate of soda, of iodine, a substance characteristic of sea-weed ; while pieces of sea-weed still undecomposed are met with here and there. On the whole, therefore, this theory, while not free from difficulties, seems to be the most worthy of acceptance as regards the origin of the nitrate deposits.¹

Appearance of Nitrate-fields.

Having thus discussed the origin of the nitrate-fields, we may now give a more detailed description of their appearance. The chief deposits at present being worked are those lying in the Pampa de Tamarugal, in the province of Tarapaca. They stretch to a distance of thirty or forty miles inland, from Pisagua southwards to somewhat beyond the town of Iquique. This huge desert, as has been already indicated, seems to be entirely destitute of all vegetation and animal life. Even in the immediately

¹ A difficulty which has not been referred to is the belief entertained by geologists that "there has been a change of climate in Northern Chili, and that there must have been more rain there formerly than there is at present. Traces of human habitations are found high up in the Cordilleras to-day. Cobs of Indian corn, axes and knives of copper tempered to exceeding sharpness, arrow-heads of agate, even pieces of cloth, are dug up in arid plains now without any trace of water for many leagues in or around them" (Russell, 'The Nitrate-Fields of Chili,' p. 290).

adjoining country the only kind of vegetation that seems to grow is a species of *acacia*. The few streams that are found in this neighbourhood are entirely fed by the melting snow from the Cordilleras. Darwin describes the appearance presented by these pampas as resembling "a country after snow, before the last dirty patches are thawed." The *caliche*, or raw nitrate of soda, is not equally distributed over the pampas. The most abundant deposits are situated on the slopes of the hills which probably formed the shores of the old lagoons. An expert can tell from the external appearance of the ground where the richest deposits are likely to be found. The *caliche* itself is not found on the surface of the plain, but is covered up by two layers. The uppermost, known technically as *chuca*, is of a friable nature, and consists of sand and gypsum; while the lower, the *costra*, is a rocky conglomerate of clay, gravel, and fragments of felspar. The *caliche* varies in thickness from a few inches to 10 or 12 feet, and rests on a soft stratum of earth called *cova*.

The Method of mining the Nitrate.

The mode in which the *caliche* is excavated is as follows: A hole is bored through the *chuca*, *costra*, and *caliche* layers till the *cova* or soft earth is reached below. It is then enlarged until it is wide enough to admit of a small boy being let down, who scrapes away the earth below the *caliche* so as to form a little hollow cup. Into this a charge of gunpowder

is introduced, and subsequently exploded. The *caliche* is then separated by means of picks from the overlying *costra* and carried to the refinery.

Composition of Caliche.

Both in appearance and composition it varies very much. In colour it may be snow-white, sulphur, lemon, orange, violet, blue, and sometimes brown like raw sugar.

The *caliche* found in the Pampa de Tamarugal contains generally about 30 to 50 per cent pure nitrate of soda; that in the province of Atacama contains from 25 to 40 per cent. The subsequent refining processes, which consist in crushing it by means of rollers and then dissolving it, need not here be described. It may be sufficient to mention that the process used is that known as systematic lixiviation, and is analogous to the method introduced by Shanks in the manufacture of soda. The chief impurity in the raw material is common salt: gypsum, sulphates of potassium, sodium, and magnesium, along with insoluble matters, are the other impurities. The manufacture of iodine, which, as has been already noticed, is found in the nitrate-beds, is also carried on at these *oficinas*.

Extent of the Nitrate Deposits.

The question of the extent of the nitrate of soda deposits is naturally one of very great interest,

especially from the agricultural point of view. M. Charles Légrange, a French writer, estimated a few years ago that they still contained about 100,000,000 tons of pure nitrate of soda. Opinions on this point differ very considerably, and it seems wellnigh impossible to arrive at any very accurate estimate.

The number of years they will last will depend, of course, on the amount of annual exportation. This, at present, falls little short of 1,000,000 tons. If this amount is maintained, they should last, according to experts, some twenty or thirty years at least. A consideration which has an important influence on this question, is the price obtained for the article. If this should be increased, it may be possible to treat the larger quantities of the inferior raw material (which at present prices are allowed to accumulate) at a profit. Undoubtedly this is what will ultimately take place, when the richer quality of the *caliche* has been exhausted.

Composition and Properties of Nitrate of Soda.

As has already been pointed out, commercial nitrate of soda contains about 95 per cent of pure nitrate of soda, or about $15\frac{1}{2}$ per cent of nitrogen, which, if calculated as ammonia, would equal 19 per cent. It is, next to sulphate of ammonia (which contains $24\frac{1}{2}$ per cent of ammonia), the most concentrated nitrogenous manure, and further, contains its nitrogen in the form most readily available for the plant's use. Its most

characteristic property is its great solubility, and consequent speedy diffusion in the soil, and the inability of the soil-particles to fix its nitrogen. In the latter respect it differs very considerably from other forms of nitrogen. Ammonia salts, though practically quite as soluble, do not diffuse in the soil so rapidly as nitrate of soda does ; for the ammonia is more or less tenaciously fixed by the soil-particles, and retained till converted by the process of *nitrification* into nitrates.

Nitrate of Soda applied as a Top-dressing.

On this account nitrate of soda is chiefly employed—and rightly so—as a top-dressing. The risk of loss by drainage is thus minimised, and the valuable nitrogen finds its rightful destination—viz., in the plant's roots.

Encourages deep Roots.

A special benefit which the diffusibility of nitrate of soda has been held to confer on the plant, is to encourage the growth of deep roots, by inducing the growing plant to send down its roots into the lower layers of the soil after the nitrate of soda. The benefit of deep roots is, of course, very great. They enable the plant to withstand the action of drought, and at the same time increase the area whence the plant may derive its nourishment. Although the value of the manure is practically entirely due to the

nitrogen it contains, it has been urged that the soda exercises a beneficial effect on the mechanical properties of the soil, by increasing its power of absorbing moisture, and in also rendering it more compact. This would partly explain how its results in dry seasons are so much better than those obtained from sulphate of ammonia. This mechanical action of nitrate can scarcely be very great when we remember the comparatively small quantity applied. Even in the driest of seasons there will always be sufficient moisture to secure the diffusion of the nitrate of soda, while the risk of loss by drainage will be reduced to a minimum. Much ignorance, as well as prejudice, has existed in the past as to the true nature of the action of nitrate of soda. Nor is this prejudice even yet entirely dispelled.

Is Nitrate an exhausting Manure?

The common charge brought against it is, that it is what has been termed an exhausting manure. This objection, to have any weight, must mean that nitrate of soda produces a crop which takes out of the soil an *abnormal* quantity of fertilising matter. But, so far as the writer is aware, no scientific evidence has ever been brought forward to support this contention. That the indiscriminate use of a manure may produce a crop in which the stem and leaves are unduly developed at the expense of the grain, or in which the quality of the crop may suffer from too rapid growth,

is, of course, a well-known fact. But as this could also be produced by an overdose of soluble phosphoric acid as well as ammonia salts, it is not a property that belongs exclusively to nitrate of soda. Probably nitrate of soda has in the past been often used in this indiscriminate way so as to produce such results. The fault, therefore, lies not in the manure, but in the mode of its application. A few remarks, therefore, on this most important subject may prove serviceable.

Crops for which it is suited.

Opinions will naturally differ as to the crops to which it is profitable to apply nitrate of soda. Its value as a manure for cereals is pretty generally admitted. Its value as a manure for roots is not, however, so universally admitted. Experiments would seem to show that such a crop as the mangold derives just as much benefit as do the cereals; while in Germany practical experience on a very large scale has demonstrated its value as a manure for beetroots. It may be generally recommended as a manure for all crops, except, perhaps, the so-called leguminous crops, such as clover, beans, peas, &c., whose ability to obtain nitrogen for themselves renders the application of expensive artificial nitrogenous manures unadvisable.

An interesting point with regard to nitrate of soda is the curious effect it seems to have on the colour of the leaves of plants. This interesting fact has been

strikingly demonstrated at the Rothamsted Experimental Station, in the contrast in the colour of the leaves of different experimental grass-plots, manured with nitrate of soda and sulphate of ammonia respectively—the plots manured with nitrate of soda being distinctly darker in hue, obviously owing to the greater production of chlorophyll or green matter. Such a depth of colour would seem to indicate a more healthy development.

Method of Application.

While opinions, therefore, will naturally differ as to the crops to which nitrate of soda will be most profitably applied, little difference of opinion exists as to the method of its application. The inability of the soil-particles to retain it, the frequency of rain, the costly nature of the manure itself, and its immediate availability as a plant-food, all point to the extreme advisability of using it as a top-dressing. Even when used as a top-dressing, it may be advisable not to apply the entire quantity all at one time. By applying it in instalments, little risk is run that, through inclemency of weather, the manure will be lost. Another point of importance in applying nitrate of soda is to secure uniform distribution. This of course is applicable to all artificial manures, but in a very special degree to nitrate of soda, because of its great value and the comparatively small quantity applied.

As the uniform distribution of one cwt. of any material over an acre of soil is by no means an easy task, the mixing of nitrate of soda with some diluent, such as dry loam, is consequently highly advisable. Common salt is often applied along with nitrate of soda. The indirect value of salt as a manure is considerable, and when applied along with nitrate, ensures its more speedy diffusion in the soil, by increasing the soil's capacity for absorbing moisture from the air.

Must be a Sufficiency of other Fertilising Constituents.

A third point of importance in applying nitrate of soda, is to see that the soil is sufficiently supplied with the other plant-foods—phosphates and potash. This is a *sine qua non*, if the nitrate is to get a fair chance. If it is desired to apply nitrate of soda along with superphosphate of lime, a word of caution is necessary against making the mixture long before it is used. The reason of this is, that a chemical action is apt to ensue, resulting in the loss of the nitric acid in the nitrate of soda. The nature of the soil is another important consideration to be taken into account. In the case of extremely loose and sandy soils, it is scarcely to be recommended as the most suitable form in which to apply nitrogen. If applied to such soils, especial care ought to be taken to minimise risk of loss. No hard-and-fast rules can be laid down as to the quantity in which it ought to be applied. This

must be regulated very much by the crop, the nature of the soil, and the quantity of other manures employed. From 1 to $1\frac{1}{4}$ cwt. may be recommended as a suitable quantity for corn crops which are otherwise liberally manured. On strong clay soils this quantity may be judiciously increased up to 2 cwt. Dr Bernard Dyer, who has experimented largely on its use as a manure for mangolds, is of opinion that an application of from 3 to 4 cwt. an acre is likely to prove thoroughly profitable; and the present writer has found in his experiments with turnips that a top-dressing of 1 cwt. amply repaid itself.

Conclusions drawn.

In conclusion, the nature and characteristics of nitrate of soda as a manure may be briefly summed up as follows:—

1. It is a whitish, crystalline salt, extremely soluble, and is quickly diffused in the soil. It should contain 95 per cent of pure nitrate of soda—*i.e.*, $15\frac{1}{2}$ per cent of nitrogen, equal to about 19 per cent of ammonia.

2. Next to sulphate of ammonia, it is the most concentrated nitrogenous manure; the relative quantities of nitrogen these two manures contain being as three is to four.

3. It contains its nitrogen in the most valuable and readily assimilable form—*i.e.*, as *nitric acid*, the form into which all other forms of nitrogen have first to be

converted before they become available for the plant's uses.

4. That, at present market prices, nitrate of soda may be safely affirmed to be the cheapest form of nitrogenous manure.

5. That nitrate of soda, in addition to its direct value as a manure, probably exercises a slight influence on the mechanical properties of the soil, by increasing its compactness and water-absorbing capacities; that it further tends to promote deep roots, and thus to increase the soil area whence the plant may derive its nourishment, at the same time rendering the plant more able to withstand the injurious influence of drought.

6. That a plentiful supply of the other manurial constituents should be present in the soil, if nitrate of soda is to exercise its full value.

7. That it may be profitably applied in the case of nearly all kinds of crops, but that great care should be taken as to the mode of its application. That this should be almost invariably as a top-dressing, and that it should be applied in several doses if possible.

8. That its effects can be regarded as lasting only during the first year after application.

APPENDIX TO CHAPTER IX.

NITRATE OF SODA.

Total Shipments from South America, 1830-1892.

Year.	Tons.	Year.	Tons.	Year.	Tons.
1830 . .	800	1870 . .	131,400	1886 . .	437,500
1835 . .	6,200	1875 . .	321,000	1887 . .	680,600
1840 . .	10,100	1880 . .	217,300	1888 . .	745,700
1845 . .	16,800	1881 . .	344,600	1889 . .	930,000
1850 . .	22,800	1882 . .	477,800	1890 . .	1,030,000
1855 . .	41,800	1883 . .	572,400	1891 . .	790,000
1860 . .	55,200	1884 . .	540,900	1892 . .	790,000
1865 . .	109,000	1885 . .	423,100		

The following tables exhibit the total imports into Europe and into the United Kingdom from the years 1873-92:—

NITRATE OF SODA, 1873-1892.

<i>Imports into Europe.</i>		<i>Imports into United Kingdom.</i>	
Year.	Tons.	Year.	Tons.
1873 . .	225,000	1873 . .	124,000
1874 . .	230,000	1874 . .	108,200
1875 . .	280,000	1875 . .	164,900
1876 . .	300,000	1876 . .	166,800
1877 . .	208,000	1877 . .	69,600
1878 . .	250,000	1878 . .	104,400
1879 . .	205,000	1879 . .	55,300
1880 . .	140,000	1880 . .	48,300
1881 . .	230,000	1881 . .	54,800
1882 . .	335,000	1882 . .	96,000
1883 . .	440,000	1883 . .	103,700
1884 . .	505,000	1884 . .	103,700
1885 . .	380,000	1885 . .	109,400
1886 . .	330,000	1886 . .	75,100
1887 . .	440,000	1887 . .	83,100
1888 . .	640,000	1888 . .	103,100
1889 . .	760,000	1889 . .	120,000
1890 . .	784,000	1890 . .	114,000
1891 . .	851,000	1891 . .	121,000
1892 . .	795,000	1892 . .	115,000

CHAPTER X.

SULPHATE OF AMMONIA.

Value of Ammonia as a Manure.

THE value of ammonia salts as a manure has been long recognised; indeed till recently ammonia was thought to be the most valuable form in which nitrogen could be applied as a plant-food—a view, we may mention, held by Liebig. While the plant, no doubt, can absorb its nitrogen in the form of ammonia,¹ as well as in other forms, as we have already pointed out in previous chapters, it is now fully recognised that ammonia salts, when applied to the soil, are converted into nitrates. Nitric acid, then, must be regarded as the most valuable, inasmuch as it is the most rapidly

¹ From experiments by Lehmann and others with buckwheat and maize, it would seem that certain plants may prefer, at certain stages of their growth, ammonia to nitrates. In the case of maize, ammonia may be preferred in the early stages of growth, while nitrates are preferred as it becomes more mature. In view, however, of our present knowledge of nitrification, it may well be doubted whether the conclusions arrived at from Lehmann's experiments can be accepted.

assimilated form of nitrogen for the plant; but next to nitric acid in value comes ammonia. Of the different forms of ammonia available for manurial purposes, the only one used to a large extent is sulphate.

Sources of Sulphate of Ammonia.

The oldest, and what is still the chief source of this valuable salt, is the gas-works, where it is obtained as one of the bye-products in the manufacture of gas. It is also obtained to a lesser extent from shale, iron, coke, and carbonising works. Bones, horn, leather, and certain other animal substances rich in nitrogen, when subjected to dry distillation, as is the case in certain manufactures, such as the manufacture of bone-charcoal for use in sugar-refineries, and the distillation of horn, &c., in the manufacture of prussiate of potash, also constitute less abundant sources.

Ammonia from Gas-works.

Coal contains on an average from a half to one and a half per cent of nitrogen. When it is subjected to dry distillation, as is done in the gas-works, the nitrogen which it contains is chiefly converted into ammonia, and, in the process of purification of the gas, is removed in the "gas-liquor,"¹ which contains about

¹ As the expense of converting the ammonia present in the ammoniacal liquor is considerable, the practice of using the liquor itself as a manure has been advocated; but as an objection to this it must be urged that, besides being so bulky a manure, the liquor contains various substances poisonous to plant-life.

one per cent of ammonia. The ammonia recovered from this liquor by distillation is then absorbed in sulphuric acid. It may be pointed out that nothing like all the nitrogen contained in the coal is recovered as sulphate of ammonia. It has been calculated that only from a fifth to a tenth is actually recovered, and many processes have been patented with a view to increasing the yield of ammonia in gas manufacture. The total production of ammonia from gas-works may be placed at little over 100,000 tons per annum for Great Britain. Mr L. Mond, F.R.S., recently drew attention to the possibility of largely increasing our supply of sulphate of ammonia from coal. As indicating what an enormous source of sulphate of ammonia we have in coal, Mr Mond calculated that its annual consumption in this country (estimated at 150,000,000 tons) would yield as much as 5,000,000 tons of sulphate of ammonia.

Other Sources.

While the ammonia produced in the manufacture of gas has long been collected, it is only of recent years that the other sources of ammonia have been developed. Next to the gas-works, the shale-works of Scotland form in this country the chief source of this valuable manure. In these works the ammonia is obtained in distilling the paraffin shale by a method somewhat similar to that in use in the gas-works. The amount of sulphate of ammonia obtained from this source is between 20,000 and 30,000 tons per

annum. Recently the ammonia has been recovered from the blast-furnace gases in iron-works — some 6000 tons being annually obtained in this way; while from coke and carbonising works the annual production is about half that amount. The combined annual production from all these sources may be put down at 140,000 tons, the total production in Europe being probably little more than 200,000 tons. In the Appendix further statistics will be found.¹

Composition, &c., of Sulphate of Ammonia.

Pure sulphate of ammonia is a whitish crystalline salt, extremely soluble in water. The commercial article, however, is generally greyish or brownish in colour, owing to the presence of slight quantities of impurities. The pure salt should contain 25.75 per cent of ammonia; but the commercial article is generally sold on a basis of 24.5 per cent. A useful test of its purity is the fact that when subjected to a red-heat it should almost entirely volatilise, leaving very little residue. The chief impurities which it is likely to contain are an excess of moisture, free acid, or the presence of insoluble matter. Certain samples contain small quantities of ammonium sulphocyanate, an extremely poisonous substance for plants. The presence of this dangerous impurity is easily detected by adding ferric chloride, which, in presence of the sulphocyanate, produces a blood-red colour. Sulphate of ammonia is

¹ See Appendix, p. 358.

thus the most concentrated of all nitrogenous manures in common use, and is for that reason the most expensive.

Application.

For this reason, as well as from the fact that it contains a speedily available form of nitrogen, sulphate of ammonia should only as a rule be applied in comparatively small quantities—100 to 125 lb. per acre.¹ It should also be applied before, but not too long before, the crop is likely to require it. The reason of this is to give it time to be converted into nitrates. The ability of the soil to retain ammonia has already been pointed out. It is not safe, however, to rely too much on the retentive power of the soil for ammonia, the conversion of ammonia into nitrates going on very quickly under favourable circumstances. It is most profitably used as a manure for cereals, and it has been found by Lawes and Gilbert in their experiments, that an increase of one bushel of wheat and a corresponding increase of straw have been obtained for every 5 lb. of ammonia added to the soil. As has been pointed out in the previous chapter, the respective merits of sulphate of ammonia and nitrate of soda depend largely on the nature of the season during which they are used. In wet seasons the sulphate is rather more favourable than the nitrate, but, on an average, nitrate of soda is probably the more valuable manure—

¹ Some crops, however, may with advantage be treated with larger quantities of sulphate of ammonia, such as mangels and potatoes.

i.e., due regard being had to the quantity of nitrogen the two manures respectively contain. In one respect sulphate of ammonia is a much more useful manure than nitrate of soda, as the nature of its action when applied to the soil permits of its being used as an ingredient of mixed manures.

Like nitrate of soda, but even to a greater extent, its most favourable action is obtained when it is applied along with other manurial ingredients. It should be applied at least a month earlier than nitrate. It has been shown that in the case of chalky soils a certain loss of ammonia in sulphate of ammonia is apt to take place, due to the action of the lime; and this leads us to point out that, in preparing mixed manures, care ought to be taken that it is not mixed with any compound containing free lime or caustic alkali, as otherwise loss of ammonia will ensue. It should never, for example, be used along with basic slag.

APPENDIX TO CHAPTER X.

NOTE (p. 355).

The following table will exhibit the production of sulphate of ammonia in this country from 1870 to 1892 :—

Year.		Tons.	Year.		Tons.
1870	. .	40,000	1882	. .	72,000
1871	. .	41,000	1883	. .	75,000
1872	. .	42,000	1884	. .	87,000
1873	. .	43,000	1885	. .	97,000
1874	. .	45,000	1886	. .	106,500
1875	. .	46,000	1887	. .	113,700
1876	. .	48,000	1888	. .	122,800
1877	. .	52,000	1889	. .	132,000
1878	. .	55,000	1890	. .	140,000
1879	. .	57,000	1891	. .	143,500
1880	. .	60,000	1892	. .	157,000
1881	. .	65,000			

The following table exhibits the sources, and the respective quantities from each source, of the last seven years' production :—

	1886.	1887.	1888.	1889.	1890.	1891.	1892.
Gas-works .	82,500	85,000	93,000	100,000	102,150	107,950	112,000
Iron-works .	4,000	5,000	5,300	6,000	5,050	6,300	12,000
Shale-works .	18,000	21,000	22,000	23,000	24,750	26,600	28,000
Coke and carbonising works }	2,000	2,700	2,500	3,000	2,300	2,800	5,000

CHAPTER XI.

BONES.

Early Use of Bones.

A MOST important manure, and one to the history of which very peculiar interest attaches, is Bones. Employed first in 1774, their use has steadily increased ever since, and their popularity as a phosphatic manure is among farmers in this country quite unrivalled. Like guano, although to a less extent, the early practice of using bones has done much to arouse interest in the problems of manuring, and to bring home to farmers the principles underlying that practice. It was from bones that Liebig first made superphosphate of lime, and the distinguished veteran experimenter, Sir John Bennet Lawes, has told us that the benefit accruing from the use of bones on the turnip crop first drew his attention to the interesting problem connected with the application of artificial manures. Bones were first used in Yorkshire. Shortly after-

wards they were applied to exhausted pastures in Cheshire. Soon their use became so popular that the home supply was found inadequate; and they were imported from Germany and Northern Europe, Hull being the port of disembarkation. So largely were they used by English farmers, that Baron Liebig considered it necessary to raise a warning protest against their lavish application. "England is robbing all other countries of the condition of their fertility. Already, in her eagerness for bones, she has turned up the battle-fields of Leipzig, of Waterloo, and of the Crimea; already from the catacombs of Sicily she has carried away the skeletons of many successive generations. Annually she removes from the shores of other countries to her own the manurial equivalent of three millions and a half of men, whom she takes from us the means of supporting, and squanders down her sewers to the sea. Like a vampire, she hangs upon the neck of Europe—nay, of the entire world!—and sucks the heart-blood from nations without a thought of justice towards them, without a shadow of lasting advantage to herself."¹

Different Forms in which Bones are used.

It may be pointed out that bones have done much to alter our system of farming, by helping to develop

¹ It is only fair to Liebig to say that when he wrote these words the practically boundless supply of mineral phosphates which we now know to exist in many parts of the world was little dreamt of.

turnip culture. Used at first in comparatively large pieces, experience gradually showed that a finer state of division facilitated their action. Yet it was long before the prejudice in favour of rough bones disappeared; and it was not till 1829 that Mr Anderson of Dundee introduced machinery for preparing $\frac{1}{2}$ -inch and $\frac{1}{4}$ -inch bones and bone-dust. In the early days of their use, bones were fermented before being used, in order to render their action more speedy when applied to the soil; and this practice still obtains to the present day in some parts of the country among farmers. This fermentation was often effected simply by mixing the bones with water, and allowing the heap to lie for a week or two. In other cases the bones were mixed with urine or other refuse matter. The most important step, however, in the history of the treatment of bones for manure was the discovery in 1840, by Liebig, of the action of sulphuric acid on them—a discovery which led to the institution of the manufacture of superphosphate of lime by Sir John Lawes. The nature of this action will be explained in the following chapter, so that we need only say here that the efficacy of the manure by treatment with sulphuric acid is more than doubled. Bones have thus been used, and still are used, in a variety of conditions, such as in the raw or green state, bruised, boiled, steamed, fermented, burned, dissolved, and broken or ground into various states of fineness, to which the names of $\frac{1}{2}$ -inch, $\frac{1}{4}$ -inch bones, bone-meal,

bone-dust, and floated bones are given. We shall now proceed to discuss the composition of bones, and investigate more exactly the nature of their action.

Composition of Bones.

The composition of bone-tissue varies considerably, and depends on the age and kind of animal to which it belongs, as well as to the part of the animal frame from which it is taken. Bones are made up of an organic and an inorganic part. By steeping a piece of bone in a dilute acid solution, the inorganic portion of the bone is dissolved out, and the organic portion, which forms the framework of the bone, is alone left. On the other hand, by submitting a bone to the action of great heat, the organic portion of the bone is driven off, and all that remains is a quantity of ash. The proportion of the organic to the inorganic matter varies considerably in different bones. The bones of young animals contain more organic matter than those of old animals. In compact bones, also, the organic matter is greater than in spongy bones. The thigh-bone, of all the bones, contains most inorganic matter. In short, bones which have to bear the greatest strain are richest in inorganic matter. Of the bones of animals, fish-bones exhibit the greatest variety of composition, some being almost entirely made up of organic matter, while others are similar in their composition to the bones of quadrupeds.

The Organic Matter of Bones.

The organic portion of bones is almost entirely made up of a substance to which the name *ossein* has been given, and which, when boiled for a long time, is converted into gelatine. This ossein, which forms on an average from 25 to 30 per cent of the weight of bones, is extremely rich in nitrogen, containing over 18 per cent.

Inorganic Portion of Bones.

The inorganic portion, which forms about 70 per cent, is made up chiefly of phosphate of lime. The dry leg-bones of oxen and sheep, according to Heintz, have the following percentage composition:—

	Per cent.
Phosphate of lime	58 to 63
Carbonate of lime	6 to 7
Phosphate of magnesia	1 to 2
Fluoride of calcium	2
Organic matter	25 to 30

According to Payen and Boussingault, raw bones contain $6\frac{1}{4}$ per cent of nitrogen and 8 per cent of water. Pure bones are thus seen to contain about 29 per cent of phosphoric acid and $6\frac{1}{4}$ per cent of nitrogen. The composition of the commercial article, however, differs very widely. This is due to the fact that bones collected from India and America, where they have been long exposed to atmospheric influences, have lost much of their organic matter. The amount of sand and earthy impurities also varies very considerably.

Treatment of Bones.

Bones are used for the manufacture of glue and gelatine. These are extracted from them by steaming the bones. The bones after treatment are used as a manure. The improvement noted in the action of the bones thus treated led to the introduction of the use of steamed bones as a manure. Raw bones are now rarely used. The fat present in raw bones retards their decomposition in the soil. Probably, as has been suggested, it forms along with lime an insoluble soap which prevents the mineral matter in the bone being dissolved by the carbonic acid of the soil. In the process of boiling or steaming a certain loss of nitrogen takes place, greater or less, according to the length of time they are boiled or steamed, and in the latter case the pressure applied. A more economical method for extracting the fat has been introduced by using benzine, but this process is not used to any extent. The loss of nitrogen in the former case is more than compensated for by their more speedy action as a manure when applied to the soil. Bone-meal of good quality contains from 45 to 55¹ per cent of phosphate of lime, and 3½ per cent of nitrogen. Our present total consumption of bones is probably little less than 100,000 tons per annum, of which about half is obtained from home collections, over 20,000 tons being annually collected in and around London alone.

¹ See Appendix, Note I., p. 371.

Action of Bones.

It is well known that bones are a slow-acting manure. They may be said to possess both a mechanical and chemical action when applied to the soil. When they putrefy, their nitrogen is slowly converted into ammonia, and carbonic acid as well as various organic acids are formed, which, acting upon the insoluble mineral matter in the bones, renders it available for plant uses. Bones thus, when applied in large quantities, may not merely act directly as suppliers of plant-food, but in the course of their putrefaction may act upon a certain amount of the inert fertilising matter of the soil and render it available. The more readily, then, bones putrefy, the more speedy will be their effect. As we have already pointed out, bones, in order to increase their efficiency, are often fermented before application. The removal of the fat is another means of increasing the rate of their action, but the fineness to which they are ground determines this more than anything else. Much ingenuity has been expended in perfecting machinery for grinding bones. At one time in Germany they were pounded in stamps similar to those used for ore. In America what has been called "floated bone" has been prepared. This bone is so fine that it actually floats in the air like flour-dust, and is made by whirling the bones against one another. The action of bones prepared in this way is of course very speedy, but the difficulty of applying a manure

in such a fine state of division to the soil is great. The expense of the process also is considerable.

The ease with which bones when ground into a fine state of division putrefy, is evidenced by the fact that bone-flour has to be salted in order to enable it to keep. Another condition which determines the rate at which the fertilising matters in bones become available is the nature of the soil. Fermentation, as we have already seen, requires a plentiful supply of air, and a certain amount, but not too much, of moisture. Consequently bones act best in medium soils—soils which are “neither too light and dry, nor too close and wet.” There can be no doubt that what gives to bones a peculiar value in the eyes of the farmer is the fact that they form a manure of a lasting character. They give what has been termed backbone to a soil. But the tendency of modern agricultural practice is to use quick-acting manures rather than slow. This has been admirably put by Professor Storer in the following words: “The old notion, that those manures are best which make themselves felt through a long series of years, is now recognised to be an error. The adage, that ‘one cannot eat the cake and have the cake’ is conspicuously true in agriculture; and just as it is the part of prudence in household or maritime economy to abstain from laying in at any one time more provisions than can be properly disposed of in a year or during a voyage, so should the farmer refrain from bringing to the land an unnecessary excess of plant-food. Such

food is liable to spoil withal in the soil, as well as other kinds of provisions that are kept too long in store. A just proportion of food, properly prepared, is the point to be aimed at always."

In view, therefore, of what has just been said, it might seem best to use bones in the form in which they are most speedily available—viz., as dissolved bones. This would be so if bones were the only source we possessed for the manufacture of superphosphate of lime; but we now have, in the various mineral phosphates, abundant and cheaper sources of this valuable manure. The opinion of leading agriculturists and agricultural chemists is rather in favour of applying bones in the undissolved condition. For one thing, it seems far from economical to utilise an expensive material such as bones for manufacturing an article which can be equally well manufactured from cheaper materials; for once the phosphate of lime is dissolved, it is equally valuable from whatever source it may be derived. Of course this is not tantamount to saying that dissolved bones as a manure are no more valuable than superphosphate. In dissolved bones we have, in addition to soluble phosphate, a considerable proportion of undissolved bone-tissue, containing a certain quantity of nitrogen and organic matter; but so far as the soluble phosphate is concerned, it seems only rational to conclude that its efficacy is equally great, whether it be derived from bone or mineral phosphate. Another reason is, that

much of the characteristic action of bones is lost by treating them with sulphuric acid. As Dr Aitken has pointed out, the germ life in the soil and in the bones gradually converts them into a form available for the nourishment of plants; but to dissolve bones with sulphuric acid is to kill out the germ life and retard the decay of any nucleus of bone in the dissolved manure.

Dissolved Bones.

Dissolved bones, however, are still manufactured. Formerly the manure called dissolved bones was often a mixture of mineral superphosphate along with undissolved bone-meal, but recent legislation has stopped the continuance of this practice. The composition of dissolved bones varies somewhat, the percentage of soluble phosphate being about 20 to 23 per cent, the insoluble amounting to from 9 to 10 per cent, and the nitrogen from $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent.¹ Another reason against dissolving bones is to be found in the difficulty experienced in dissolving their phosphate. Bones, especially when raw, are not easily acted upon by acids.

Crops suited for Bones.

Bones are commonly regarded as being specially beneficial to pasture-land, to which they are applied as a top-dressing. Turnips, tobacco, potatoes, vines, and hops are also much benefited by the application

¹ See Appendix, Note II., p. 371.

of bones. In America, mixed with wood-ashes (the chief manurial constituent of which is potash), they have been extensively used as a substitute for farm-yard manure, and have been applied at the rate of 5 to 6 cwt. per acre. In Saxony, according to Professor Storer, 1 cwt. of fine bone-meal is worth as much as 25 to 30 cwt. of farmyard manure.

Bone-ash.

The ash which is left on burning bones used to be an article of considerable manurial importance. It is still imported from South America in some quantity, and is used chiefly in the pottery industry. It is occasionally still used to a limited extent for the manufacture of high-class superphosphates. It is extremely rich in phosphate of lime, of which it contains between 70 and 80 per cent; but of course it is devoid of nitrogen.¹ Bone-ash is best used in the dissolved form, as it possesses no characteristic action such as is possessed by bones.

Bone-char or Bone-black.

When heated in a closed retort, bones are not converted into bone-ash, but into a body called bone-char. This body is similar in composition to bone-ash, except for a certain percentage of charcoal—amounting, on an average, to 10 per cent. It contains but little nitrogen and other organic matter. Bone-black or

¹ See Appendix, Note III., p. 372.

bone-char is an article which is prepared in enormous quantities for use in sugar-refineries, where it is used in the purification of sugar. After use it may be renovated by submitting it to heat; but as this process gradually lessens the percentage of carbon it contains, after a certain period it becomes too poor in this substance for efficiently acting as a filter. When this takes place it is technically known as spent char, and is used for the manufacture of superphosphates. Spent char is a highly phosphatic substance, being very little poorer than bone-ash, and containing about 70 per cent of phosphate of lime.¹

¹ See Appendix, Note IV., p. 372.

APPENDIX TO CHAPTER XI.

NOTE I. (p. 364).

The following analysis will serve to show the composition of bone-meal:—

Moisture	10.43
*Organic matter	32.30
Phosphate of lime	48.40
Carbonate of lime, magnesia, &c.	7.20
Insoluble siliceous matter	1.67
	<hr/>
	100.00

*Containing:—

Nitrogen	3.71
Equal to ammonia	4.51

NOTE II. (p. 368).

COMPOSITION OF DISSOLVED BONES.

The accompanying analysis may be taken as representing the average composition of dissolved bones:—

Moisture	10.10
*Organic matter and water of combination	29.34
Monobasic phosphate of lime	11.23
(Equal to tricalcic phosphate rendered "soluble")	17.58)
Phosphate soluble in ammonium citrate	14.02
Insoluble phosphate of lime	1.88
Calcium sulphate, magnesia, alkalies, &c.	30.23
Sand	3.20
	<hr/>
	100.00

*Containing:—

Nitrogen	2.62
Equal to ammonia	3.18

COMPOSITION OF COMPOUND BONES.

The following analysis illustrates the composition of compound bones:—

Moisture	8.10
*Organic matter and water of combination	37.22
Monobasic phosphate of lime	13.68
(Equal to tricalcic phosphate rendered "soluble")	21.42)
Insoluble phosphate of lime	10.48
Calcium sulphate, magnesia, alkalies, &c.	26.02
Sand	4.50
	<hr/>
	100.00
*Containing:—	
Nitrogen	1.90
Equal to ammonia	2.30

NOTE III. (p. 369).

As showing the composition of bone-ash, the following analysis may be quoted:—

Moisture . . . . .	.25
Organic matter . . . . .	.85
*Phosphoric acid	35.56
Lime	47.09
Magnesia, alkalies, &c.	9.80
Sand	6.45
	<hr/>
	100.00
*Equal to tricalcic phosphate	77.63

NOTE IV. (p. 370).

Composition of bone-char (on dry sample):—

Carbon	10.51
Calcium and magnesium phosphates, calcium fluoride, &c.	80.21
Calcium carbonate	8.30
Calcium sulphate . . . . .	.17
Ferric oxide . . . . .	.12
Silica . . . . .	.34
Alkaline salts . . . . .	.35
	<hr/>
	100.00

CHAPTER XII.

MINERAL PHOSPHATES.

IN this chapter we shall give an account of the more commonly occurring mineral phosphates. In Chapter V., where we discussed the position of phosphoric acid in agriculture, it was pointed out that mineral phosphates were very abundant, and that large deposits of them were found in many parts of the world.

Coprolites.

Reference may first be made to the so-called coprolites or phosphatic nodules which have been found in great abundance in the greensand formation, in the crag of the eastern counties, and in the chalk formation of the southern counties. These coprolites are rounded nodules, and are composed of the fossil excrements and remains of ancient animals. They are found in large quantities in Cambridgeshire, and were discovered by Dr Buckland many years ago. The history of their discovery is not a little curious.

The manurial properties of road-scrapings in parts of Cambridgeshire were noticed, and on being examined were found to be in part composed of phosphate of lime, derived from phosphatic nodules dug out of the underlying greensand, and used for the purpose of repairing roads. Professor Henslow first drew attention to them at a meeting of the British Association held in Cambridge in 1845, and pointed out that they contained about 60 per cent of phosphate of lime. They were also found in enormous quantities in Suffolk, Norfolk, Bedfordshire, and Essex, and were for a long time largely used in the manufacture of superphosphate, but of late years have not been used to anything like the same extent, owing to the fact that there are richer and cheaper sources of phosphate of lime available. In 1887 about 20,000 tons of coprolites were raised. The richest were those obtained in Cambridge, while those got from Bedfordshire were about the poorest. Deposits have also been found in France and other countries. The average amount of phosphate of lime in English coprolites is between 50 and 60 per cent, while the French contain about 45 per cent.

Canadian Apatite or Phosphorite.

We have already referred in Chapter V. to large deposits of apatite or phosphorite found in Canada. The Canadian mines commenced to be worked about

fifteen years ago, and the output now amounts to nearly 25,000 tons per annum.¹ A portion of this goes to the United States; the rest, amounting to about 20,000 tons, being shipped to England, whence it is again exported to Hamburg and other places.² It contains from 70 to 80 per cent of phosphate. Deposits are also found at Estremadura in Spain, and in Norway.

Estremadura or Spanish Phosphates.

Large deposits of phosphate have long been known to exist at Estremadura in Spain, and the mines at Caceres have been worked on a large scale for seventeen years, and about half a million tons have been raised. In 1882 the imports into this country amounted to over 56,000 tons; but latterly they have only been about a fourth of this amount. Dr Dauberry visited the deposits in 1843, and wrote a most interesting account of them. They do not seem, however, to have been imported for purposes of superphosphate manufacture till a number of years afterwards. Of Estremadura phosphate there are three classes, containing respectively 50, 60, and 70 per cent of phosphate of lime, the lowest quality being the commonest.³

¹ Since the discovery of the Florida deposits of phosphate, the working of the Canadian mines has been practically abandoned.

² See Appendix, p. 381.

³ These phosphates are now no longer worked.

Norwegian Apatite.

This apatite has ceased to be imported of late years, owing to a duty on exportation.

Charleston or South Carolina Phosphate.

For a number of years these deposits have formed the chief source of phosphate of lime used in the manufacture of mineral superphosphates in this country (in fact they have furnished two-thirds of our phosphate supply during recent years). Discovered twenty-five years ago, some four to five million tons have already been shipped. About half a million tons were raised in 1886 from these mines, which are the most abundant in the world. There are two kinds—the so-called “land” and “river” phosphates. The former contains more oxide of iron and alumina, and is therefore less pure than the latter, in which the iron and alumina do not exceed 2 per cent. The river phosphate is dredged from the Bull, Coosaw, and Beaufort rivers. Of phosphate of lime it contains from 50 to 60 per cent. It is generally sold in three grades—50 to 52 per cent, 55 to 56 per cent, and 58 to 60 per cent of phosphate of lime. It will thus be seen to be incapable of producing very high-class superphosphates—*i.e.*, containing more than 30 per cent “soluble” phosphate. This point will be more intelligible when we describe the manufacture of superphosphate. The demand for these phosphates

in the United States has increased enormously in recent years, owing to the increase in the quantity of manure used.

Belgian Phosphate.

Another very important source of mineral phosphates are deposits discovered some years ago in Belgium near Mons. These phosphates are of different qualities, and are found, some in layers near the surface in pockets forming the richest class, and containing from 45 to 65 per cent of phosphate, and some in the form of a friable phosphatic rock, the so-called *craie-grise* (phosphatic chalk), containing from 25 to 35 per cent of phosphate of lime. The higher quality of Belgian phosphate is pretty well exhausted, and it is the second class that forms the bulk of the ordinary Belgian phosphate at present exported. The commercial article contains about 35 to 40 per cent of phosphate, and about 45 per cent of carbonate of lime. The fact of its poor quality, together with the large percentage of carbonate of lime it contains, renders its adoption alone in the manufacture of superphosphate unsuitable. Attempts have been made to get rid of a portion of this carbonate of lime and to raise the percentage of phosphate. For this purpose the phosphate has been calcined, but this was soon found to be a great mistake. Other means have been adopted, with the result that the percentage has been increased to 50

per cent. It is consequently used in small quantities as a drier, for which it is peculiarly suited on account of its carbonaceous nature, along with the higher-class phosphates. In the year 1886 about 145,000 tons of this phosphate were raised, of which about 45,000 tons were imported into the United Kingdom.

Somme Phosphate.

Still more recently a discovery of phosphate deposits has been made in the Somme and Pas de Calais departments in the north of France, adjoining, and similar in character to, the Belgian deposits. The only difference between Belgian and French phosphates is, that the latter is of a higher quality, and contains from 50 to 80 per cent of phosphate of lime. A very large demand for these phosphates sprang up, and in 1888, although they had only been worked for some two years, no less than 150,000 tons had been raised, of which about one-half contained from 70 to upwards of 75 per cent. There are four grades in the market, containing 55 to 60, 60 to 65, 70 to 75, and 75 to 80 per cent of phosphate of lime. The highest quality furnishes the chief material for the manufacture of high-grade superphosphates.

*Florida Phosphate.*¹

During the last few years large quantities of phos-

¹ These deposits were discovered a few years ago ; and as they are of considerable extent and high quality, have entirely revolutionised

phates have been imported from Florida. These are of different qualities, the land rocks now imported containing from 70 to 80 per cent of phosphate of lime, and the river phosphate about 60 per cent. The latter class are similar in composition to the best South Carolina river-phosphates, which they much resemble.

Lahn Phosphate.

Phosphate deposits were found at Nassau in Germany in 1864; but as the phosphate contained a considerable proportion of iron and alumina, they are not used in this country now, although they are in Germany for double superphosphate manufacture.

Bordeaux or French Phosphate.

Similar in quality to Lahn phosphate is that obtained in the neighbourhood of Bordeaux.

Algerian Phosphate.

Excellent phosphates are now being sent from Algeria—some cargoes being as rich as 70 per cent.

Crust Guanos.

We have already referred to the guanos in the chapter on Guano. They are also known under the name of Caribbean phosphates, and come from the West India Islands. The chief kinds are Aruba, Curaçao, Sombrero, and Navassa, the Great Cayman, the phosphate market. About 300,000 tons are now annually raised in Florida.

Redonda, and Alta Vela. Most of them are of high quality, containing from 60 to 80 per cent of phosphate, and are thus suited for the manufacture of high-class superphosphates. Some of them, however, contain a considerable proportion of iron and alumina, and are not suitable for this purpose. The Redonda and Alta Vela phosphates consist chiefly of phosphate of alumina.

Value of Mineral Phosphates as a Manure.

While it is commonly regarded as unadvisable to use mineral phosphates directly as phosphatic manures, it may well be questioned how far such an opinion is warranted by actual experience. Professor Jamieson of Aberdeen, in his interesting and valuable experiments, has drawn attention to the fact that coprolites in a fine state of division are an extremely valuable source of phosphoric acid for crops, and are a more quickly available source than is commonly supposed. Experiments conducted elsewhere with ground coprolites and other mineral phosphates corroborate Professor Jamieson's conclusions. The successful use of Thomas-phosphate has drawn attention to the possibility of profitably applying undissolved mineral phosphate to the soil; and no doubt the practice may in future years be increased. At present, however, with the exception of Thomas-phosphate, mineral phosphates alone are used for conversion into superphosphate.

THE FOLLOWING TABLE SHOWS THE IMPORTS OF PHOSPHATES INTO THE UNITED KINGDOM, AND THE COUNTRIES OF PRODUCTION, DURING THE YEARS 1885-92.

*** Florida phosphate.**
Carolina phosphate.

CHAPTER XIII.

SUPERPHOSPHATES.

As was mentioned in the chapter on Bones, Liebig in the year 1840 discovered that the effect of adding oil of vitriol, or sulphuric acid, to bones was to render the phosphate they contain soluble. This discovery marked an epoch in the history of artificial manures, and laid the foundation of the now enormous manufacture of superphosphate. In 1862 the juries of the London International Exhibition published an elaborate report containing an interesting article on the manure trade of Great Britain, in which it was stated that the annual quantity of superphosphate then made amounted to from 150,000 to 200,000 tons. Now it may be placed not far short of a million tons. Probably that made in the United States is considerably more. In the first instance, superphosphate was manufactured by Sir John Lawes from spent bone-char. This was superseded by coprolites and Estremadura phosphorite,

Suffolk coprolites being for many years the chief material employed. This in turn was succeeded by the richer Cambridge coprolites, but of late years coprolites have practically ceased to be a source of superphosphate, the other mineral phosphates mentioned in the previous chapter—such as the South Carolina, Belgian, Somme, &c., phosphates—taking their place.

Manufacture of Superphosphate.

The manufacture of superphosphate is of too technical a nature to permit of discussion in a work of this kind. It is important, however, that the general principles underlying the process of manufacture and the chemical changes in the phosphate taking place during the process be clearly understood. In the first place, great importance attaches in the manufacture of the superphosphate to the fineness of division of the raw material, and much ingenuity has been spent on apparatus designed for this purpose. The difficulty of grinding the phosphate varies, of course, with the nature of the material used—apatite, for example, being much more difficult to reduce to the necessary fineness than phosphatic guano. The finer the state of division, the more complete will be the decomposition of the phosphate by the acid. Mr Warrington recommends that for first-class work the powder should be so fine as to admit of it passing through a sieve of eighty wires to the inch. After the phosphate is reduced to

powder, it is mixed with acid. This takes place in the mixer, which is generally in the form of an iron cylinder furnished in the centre with a revolving shaft, the sulphuric acid used being the ordinary chamber acid (sp. gr. 1.57). Whatever strength of acid is used, there must be a certain quantity of water present to form gypsum. It is to the formation of gypsum in the resulting product that the dryness of the superphosphate is due. The proportion of sulphuric acid used depends on the composition of the phosphate; and here it may be pointed out that the presence of much carbonate of lime is a most important factor in determining the quantity of acid required. The reason of this is, that where carbonate and phosphate of lime are present together, sulphuric acid first acts upon the carbonate, and it is not till this is wholly decomposed that the phosphate can be acted upon. Hence mineral phosphates with a large percentage of carbonate of lime do not constitute such an economical material for the manufacture of superphosphate as those in which the percentage of carbonate is small.¹ A certain amount of heat is necessary for the purpose

¹ This holds true, it may be mentioned, with regard to the application of certain manures, such as bone-char, to the soil. Bone-char was for a long time used in France as a manure without being dissolved. The action of such a manure, containing a considerable percentage of carbonate of lime, is slower than its action would be were it pure phosphate of lime, as the carbonate of lime is first acted upon (as in the case of superphosphate manufacture) by the soil acids.

of enabling a quick decomposition to take place. For this purpose the sulphuric acid added has been previously heated. In the ordinary manufacture of superphosphate, however, this is not considered necessary, as the heat developed by the chemical action between the phosphate and the acid is sufficiently great. The phosphate, after being thoroughly mixed with the acid, is discharged into what is technically known as the pit, a chamber built of brick or concrete. The mixture, which is in a fluid state when it enters the pit, very soon hardens, and is dug out in a day or two. It is next reduced to powder in a disintegrator, and is then ready for use as a manure.

Nature of the Reaction taking place.

In order to clearly understand the nature of the reaction which takes place when sulphuric acid is added to a phosphatic material, it may be well to say a word or two on the composition of the different compounds of lime and phosphoric acid.

Phosphates of Lime.

In the various phosphatic manures used in agriculture there are four different kinds of phosphates. In the commonest form, popularly called bone-phosphate, which is the form in which lime and phosphoric acid are combined in bones, guano, and the ordinary mineral phosphates, the lime and phosphoric acid are combined in the form of what is known as

tribasic phosphate of lime, or tricalcic phosphate—that is to say, for every equivalent of phosphoric acid there are three equivalents of lime. This may be represented as follows:—



Or we may also say that for every 142 parts by weight of phosphoric acid there are 168 parts by weight of lime in this form of phosphate. This is the least soluble form of phosphoric acid,¹ and is the form generally referred to in commercial analyses as insoluble phosphate. When this phosphate is acted upon with sulphuric acid, a soluble phosphate is formed, as Liebig first showed, to which the name superphosphate has been given, and which is also known as monobasic phosphate of lime, or monocalcic phosphate. This compound may be represented as containing, instead of three equivalents of lime, only one, the other two equivalents being replaced by water. This compound may be represented as follows:—

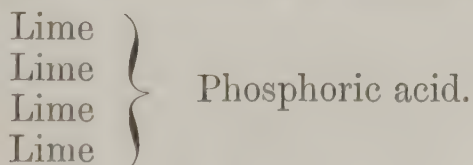


¹ The solubility of tribasic phosphate, of course, is not always equal in different manures. For example, the phosphate in apatite, owing to the crystalline structure of that mineral, is not nearly so soluble as the phosphate in phosphatic guanos, although in both cases its chemical composition is practically the same.

In it, for every 142 parts of phosphoric acid, there are only 56 parts of lime. It is soluble in water, and gives to the commercial article known as superphosphate of lime its value. Intermediate in composition between these two phosphates there is another known as precipitated phosphate of lime, or dicalcic phosphate (the same as reverted phosphate), which contains two equivalents of lime and one equivalent of water as follows:—



This compound contains, for every 142 parts of phosphoric acid, 112 parts of lime; and in solubility occupies an intermediate position. Lastly, there is a fourth compound of lime and phosphoric acid, which only occurs in one phosphatic manure—viz., phosphatic slag, in which indeed it was first discovered—which consists of four equivalents of lime to one of phosphoric acid, to which the name tetrabasic phosphate of lime or tetracalcic phosphate has been given. Its composition may be illustrated as follows:—



Or, for every 142 parts of phosphoric acid, there are 224 parts of lime. Contrary to what we might expect, this phosphate is less insoluble than the ordinary tribasic or bone phosphate. This may be owing to

the fact that, in the tetrabasic phosphate, there is more lime present than that which the phosphoric acid can retain with strong chemical affinity.¹ In the manufacture of superphosphate the tribasic phosphate is converted into the soluble phosphate—the lime, which was formerly in combination with the phosphoric acid, uniting with the sulphuric acid, and forming gypsum.² It was till recently supposed that soluble phosphate and gypsum were the only two resulting products of this decomposition. It has been recently shown, however, by Ruffle and others, that this is not, strictly speaking, the case, and that probably a large proportion of free phosphoric acid is formed ; in fact, it seems probable that in the first stage of the reaction, only phosphoric acid is produced, and that this subsequently acts upon the undecomposed phosphate, with the production of monocalcic phosphate.³ The amount of sulphuric acid which experience has shown it is necessary to add for the successful and economical manufacture of superphosphate, depends on the composition of the raw material employed. The larger the percentage of tribasic phosphate, the larger the quantity

¹ For formulæ of the different phosphates, see Appendix, Note I., p. 398.

² For chemical formulæ, showing reaction, see Appendix, Note II., p. 398.

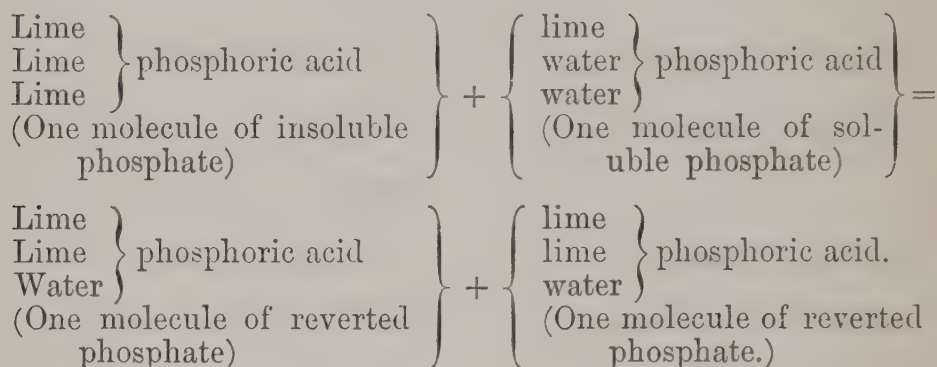
³ Of course it is well known that free phosphoric acid is obtained by acting upon phosphate of lime with an excess of sulphuric acid ; but the point above referred to as having been recently discovered is, that when phosphate of lime is acted upon, even by a small quantity of sulphuric acid, free phosphoric acid is formed.

of sulphuric acid required for its decomposition; but sometimes even a poor phosphate consumes a large amount of sulphuric acid. This is the case where much calcium carbonate or fluoride is present in the raw phosphate, as both of these compounds require a quantity of acid for their decomposition, which takes place before the decomposition of the phosphate. Hence phosphates rich in carbonate of lime are not well suited as economical materials from which to manufacture superphosphate.

Reverted Phosphates.

A change which is apt to take place in superphosphate after its manufacture is what is known as reversion of the soluble phosphate. Thus it is found that on keeping superphosphate for a long time the percentage of soluble phosphate becomes less than it was at first. The rate at which this deterioration of the superphosphate goes on varies in different samples. In a well-made article it is practically inappreciable, whereas in some superphosphates, made from unsuitable materials, it may amount to a considerable percentage. The causes of this reversion are twofold. For one thing, the presence of undecomposed phosphate of lime may cause it. This source of reversion, however, is very much less important than the other, which is the presence of iron and alumina in the raw material. When a soluble phosphate reverts, what takes place is the conversion of the monocalcic phos-

phate into the dicalcic. Now in the first case, where reversion is due to the presence of undecomposed phosphate, the action taking place may be represented as follows:—



It may be mentioned, however, that reversion from this cause probably takes place to a very slight extent in practice.¹ Where reversion is due to the presence of iron and alumina in the raw material, the nature of the reaction is not well understood, and is consequently not so easily demonstrated as in the former case. Where iron is present in the form of pyrites, or ferrous silicate, it does not seem to cause reversion. It is only when it is present in the form of oxide—and in most raw phosphatic materials it is generally in this latter form²—that it causes reversion in the phosphate.

¹ For chemical formulæ showing this reversion, see Appendix, Note III., p. 399.

² For chemical theories on reversion of soluble phosphate by iron and alumina, see Appendix, Note IV., p. 399.

Value of reverted Phosphate.

The value of reverted phosphate is a subject which has given rise to much dispute among chemists. That it has a higher value than the ordinary insoluble phosphate is now admitted; but in this country, in the manure trade, this is not as yet recognised. At first it was thought that it was impossible to estimate its quantity by chemical analysis. This difficulty, however, has been overcome, and it is generally admitted that the ammonium citrate process furnishes an accurate means of determining its amount. Both on the Continent and in the United States reverted phosphate is recognised as possessing a monetary value in excess of that possessed by the ordinary insoluble phosphate. The result is, that raw phosphates containing iron and alumina to any appreciable extent are not used in this country, although they do find a limited application in America and on the Continent.

Composition of Superphosphates.

Superphosphates as manufactured may be divided, generally speaking, into three classes—viz., low class, medium, and high class. The ordinary or medium class contains from 25 to 27 per cent of soluble phosphate; and here it may be pointed out that by soluble phosphate is meant the percentage of tribasic phosphate which has been dissolved—not, as might at first sight be supposed, the percentage of monocalcic

phosphate. The lower-class superphosphates are those containing less than 25 per cent, generally 23 to 25 per cent, of soluble phosphate; while the high-class superphosphate may contain from 30 to 45 per cent. For the manufacture of high-class superphosphate only a certain number of raw phosphates are available, such as Curaçao and Somme phosphates, phosphatic guanos, bone-char, &c. Certain processes have been patented for the manufacture of even more concentrated superphosphates, and by them phosphates containing as much as 40 per cent of soluble phosphoric acid—*i.e.*, equal to 87 per cent of soluble phosphate—have been prepared. To this class belongs the so-called double superphosphate, manufactured at Wetzlar in Germany. Such a concentrated form of manure is naturally very expensive to manufacture, and is hardly to be recommended for home consumption. Where, however, manures have to be conveyed long distances, and the freight is consequently very high, such a concentrated article may be found most economical.

Action of Superphosphates.

When superphosphate is applied to the soil it is converted into an insoluble state. In short, the process of reversion is carried on on a wholesale scale. This is due to the lime, iron, and alumina salts which the soil contains. In all probability the phosphate is finally converted into a hydrated ferric or aluminic

phosphate, in which form it is gradually acted upon by the sap of the plant-roots as required. This being the case, it may be asked, Why is superphosphate so much more rapid in its action than insoluble phosphate; or why should we be at the trouble and expense of dissolving the phosphate if it has to become insoluble again in the soil? This question is one of very great importance, for the answer to it furnishes, in our opinion, the key to the whole phosphate question. When superphosphate is added to the soil, being soluble in water, it is soon dissolved and carried down by the rain into its pores, and becomes thoroughly mixed with the soil-particles. It is thus soon fixed in the soil, beyond the risk of being washed away. The result is, that the phosphate is obtained in a state of division infinitely more minute than could ever be obtained by mechanical grinding, and is, further, most intimately mixed with the particles of the soil. It is this intimate mixture of the phosphate with the particles of the soil, and its minute state of division, that constitute the only reason for rendering superphosphate superior in its action to even the most finely ground insoluble phosphates. This opinion is supported by the fact, that although the chemist has imitated nature in this matter so far as to manufacture precipitated phosphate, he has failed, as a rule, in getting as favourable results with it as with superphosphate. Although the mechanical state of division of the

manufactured precipitated phosphate is probably as fine as that obtained by nature from the superphosphate, it is impossible to obtain so intimate a mixture with the soil-particles, and hence the results obtained are different. For these reasons it will be easily seen that the rate of action of the superphosphate must always be quicker than that of any other form of phosphatic manure. The phosphate is everywhere distributed in the soil. The plant-roots are thus furnished with a continuous supply throughout their growth, and micro-organisms, which require for their development a supply of this necessary plant-food, are propagated. A regularity in the plant's growth is thus secured, which is of great importance. But while admitting this, there are many cases in which this greater quickness of action does not render soluble phosphate the most economical form. The nature of the crop, as well as the nature of the soil, may in many cases be such as to render the application of the cheaper insoluble phosphate more economical. It is imperative that the early growth of some crops be hastened as much as possible by a ready supply of easily assimilable plant-food, in order to enable them to successfully sustain the attack of certain pests to which they are liable to succumb. This, for example, is notably the case with turnips. In such a case there can be no doubt that the value of soluble phosphate to the young plants is very great, as it enables them to survive this critical period.

Action of Superphosphate sometimes unfavourable.

But even in this case there may be other conditions which render insoluble phosphate a preferable manure. Such a case is where the soil is of a very light nature and is deficient in lime. In this case the acid superphosphate, not having the necessary base to combine with, may prove even hurtful to the young plants. According to the late Dr Voelcker, a concentrated superphosphate may produce a smaller crop than a fertiliser containing only a quarter as much soluble phosphoric acid, when applied to root-crops on sandy soils, greatly deficient in lime. Cases such as the above, however, are extremely rare; and we may say that, in the case of root-crops generally, superphosphate must be regarded as of special value.

Application of Superphosphate.

In any case, superphosphate ought to be applied to a soil some time before it is likely to be assimilated by the plant, in order to allow neutralisation of its acid character to be fully effected before the plant's roots come in contact with it. Thus Professor S. W. Johnson, one of the greatest living American authorities, states it as his opinion that recent investigations tend to show that soluble and reverted (or precipitated) phosphates are, upon the whole, about equally valuable as plant-food, and of nearly equal commercial value. But as Sir John Lawes, in quoting Professor Johnson

to the above effect, remarks, this opinion is based on an experience of American agriculture, in which country soluble phosphate is chiefly applied to cereal crops, while in this country it is chiefly applied to turnips. In the case of cereal crops, the importance of a speedy early growth is not so great, as we have already pointed out, as it is in turnips, where the danger to the young plants from the ravages of the turnip-fly is such that the growth of even a day or two may make a very considerable difference.

Value of Insoluble Phosphate.

A consideration of the action of superphosphate, then, throws a good deal of light on the conditions which determine the value of insoluble phosphates when applied to the soil, and shows that the state of division, intimacy of mixture with soil-particles, and the nature of the soil, are the determining factors. Insoluble phosphates, as we shall have occasion to see when discussing basic slag, have their best action on soils poor in lime and rich in organic matter. Tables have been drawn up with a view to furnishing a guide for the value of phosphoric acid in different manures. In the Appendix¹ we give those of Wolff for 1893, and an American table, drawn up for 1892. The comparative values of mineral phosphates, as well as Peruvian guano and bone-dust, will be further referred to in the following chapter.

¹ See Appendix, Note V., p. 400.

Rate at which Superphosphate is applied.

The rate at which superphosphate is applied to the soil varies in different parts of the country. In England 2 to 3 cwt. per acre is considered an average dressing; whereas in many parts of Scotland it is applied in as large quantities as 6 to 8 cwt. per acre to the turnip crop. The reason why so much heavier dressings can be advantageously given in northern parts of this country is owing to the much longer period of unchecked growth. In the more southern districts, where the rainfall is less, mildew is almost certain to appear when the sowing is as early as required for a maximum crop. With it, as with other manures, the quantity must be determined by the conditions of its application, and the amount of other manure applied.

APPENDIX TO CHAPTER XIII.

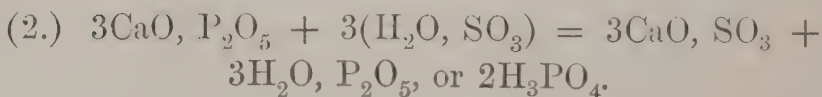
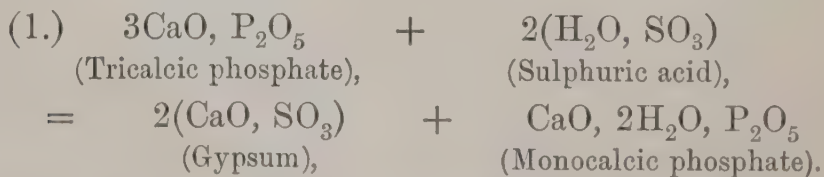
NOTE I. (p. 388).

The formulæ, and molecular and percentage composition, of the different phosphates, are given in the following table :—

		Composition in terms of—						
		Molecular weight.				Per cent.		
		Lime.	Water.	Phos- phoric acid.	Total.	Lime.	Water.	Phos- phoric acid.
Tri- or bone- phosphate.	$3\text{CaO}, \text{P}_2\text{O}_5$	168	0	142	310	54.19	0.00	45.81
Bi- or di- phos- phate.	$2\text{CaO}, \text{H}_2\text{O},$ P_2O_5	112	18	142	272	41.18	6.61	52.21
Mono- or super- phosphate.	$\text{CaO}, 2\text{H}_2\text{O},$ P_2O_5	56	36	142	234	23.93	15.39	60.68

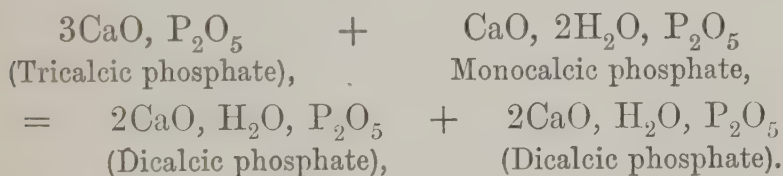
NOTE II. (p. 388).

When sulphuric acid is added to tricalcic phosphate, the following reaction takes place :—



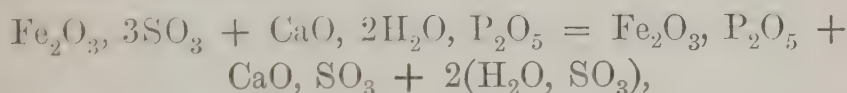
NOTE III. (p. 390).

This equation gives the chemical reaction taking place when soluble phosphate is reverted, owing to the presence of undissolved phosphate :—

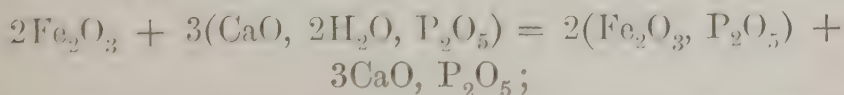


NOTE IV. (p. 390).

“Just what the reactions are which are produced by the iron and alumina compounds has never been made out very clearly. But some idea of them may be gained from the following suggestions, which were thrown out by the English chemist Patterson. Suppose the sulphuric acid has dissolved a quantity of iron or alumina, then we may have the reaction :—



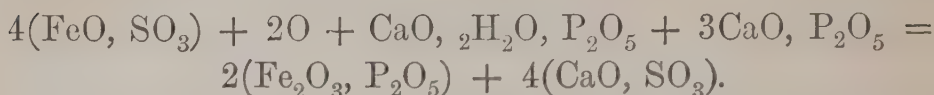
and the free acid thus formed would proceed to dissolve more iron or alumina from the rock that had previously escaped decomposition, and the reaction here formulated would occur again and again. Here we have a cumulative process continually increasing the quantity of insoluble $\text{Fe}_2\text{O}_3, \text{P}_2\text{O}_5$, and diminishing in the same proportion the soluble P_2O_5 . Again, we may have simply—



where three molecules of the soluble phosphoric acid are made to revert to the insoluble state at one blow.

“In case the iron in the original rock were in the state

of ferrous oxide, perhaps the following reaction might occur:—



In all these equations, except the last, alumina would serve as well as oxide of iron.”—(*Vide* Storer’s ‘Agricultural Chemistry,’ vol. i. pp. 276, 277.)

NOTE V. (p. 396).

The following table shows the relative trade values of phosphoric acid in different manures:—

I.—WOLFF, 1893.

Phosphate soluble in water (as in super)	100
Precipitated phosphate, Peruvian guano	92
Reverted phosphate, finest steamed bone-dust, fish-guano, poudrette	83
Phosphatic guanos (Baker Island), wood-ashes	75
Coarser bone-dust, powdered animal charcoal, bone-ash	67
Coarse fragments of bone, powdered phosphorite and coprolite, Thomas-slag, farmyard manure	33

II.—AMERICAN, 1892.

Phosphate soluble in water	100
Phosphate soluble in ammonium citrate	94
Fine bone-dust, powdered fish	94
Fine medium bone	74
Medium bone	60
Coarse bone	40

CHAPTER XIV.

THOMAS-PHOSPHATE OR BASIC SLAG.

IN this substance we have a most important addition to our phosphatic manures. It has been in the market since 1886, and the consumption alone in Germany in 1887 amounted to nearly 300,000 tons. In this country it is only now beginning to be used to any extent.

Its Manufacture.

Thomas-slag is a bye-product obtained in the manufacture of steel by what is known as the "basic" process. In the year 1879 an improvement in the well-known "Bessemer" process was patented by Messrs Gilchrist & Thomas. It must be explained that in the manufacture of steel from pig-iron certain impurities in the raw material have to be got rid of in order to produce a good steel. Among these impurities one of the most important is *phosphorus*. This is owing to the fact that even a very small percentage of phosphoric acid in steel has the effect of

rendering it brittle. The extraction of the phosphorus from the raw material was formerly, however, attended with very serious difficulties, and had the effect naturally of rendering steel a costly article, inasmuch as only the purer kinds of pig-iron could be used for the purpose.

By the introduction in 1879, however, of the "Thomas - Gilchrist" or "basic" process, these difficulties were very largely overcome, and the employment of even such impure irons as the Cleveland (containing comparatively a large percentage of phosphorus) was rendered possible, and the price of steel consequently generally very much reduced. The process consists of submitting the molten pig-iron to a very great heat in a pear-shaped vessel (known technically as the "converter"). This is open at the top, and is supported on hinges, which permit of its being moved so as to pour off the scum which rises to the surface at the end of the operation, and which, we may explain, consists of "basic slag." In the original process the sides of the "converter" were lined with fire-bricks, consisting largely of silica. This process was known as the "acid" process. In the "Thomas-Gilchrist" process, however, the sides of the "converter" are lined with *lime* (dolomitic limestone being largely used), lime being also added to the pig-iron. An air-blast is injected through the molten mass, and the impurities are burnt, or oxidised as it is chemically termed. The phosphorus in the

iron is thus converted into phosphoric acid, and, uniting with the lime, forms phosphate of lime, which rises, as we have already said, to the surface in the form of a scum, and is separated from the steel by being poured off.

Not at first used.

This, then, is how the *Thomas-slag* is obtained. It did not seem, however, for some years after the introduction of this ingenious process, to have struck any one that this rich phosphatic bye-product might prove a valuable addition to our artificial fertilisers. The result was, that the *Thomas-slag* was treated as another of the only too numerous valueless bye-products which seem to be necessarily incidental to most of our chemical and other manufactures, and was allowed to accumulate in large quantities without being used for any purpose.

Discovery of its Value.

In 1883 some short articles published in Germany on the subject were the means of first drawing the attention of the public to its importance as a manure. During the years 1884 and 1885 numerous experiments were carried out on the subject in the same country; and from then up till the present hour it has become more and more extensively used in Germany, till in 1887, as already stated, its consumption amounted to nearly 300,000 tons.

Composition.

It consists mainly of phosphate of lime, silicate of lime, free lime, free magnesia, and oxides of iron and manganese. Its composition, of course, naturally varies ; but the following may be taken as an average analysis :¹—

	Per cent.
*Phosphoric acid	17
Lime in combination with phosphoric, silicic, sulphuric, and carbonic acids	40
Free lime	15
Oxides of iron	12
*Equal to tricalcic phosphate	37

As a rule, the phosphoric acid varies considerably, ranging from 10 to 20 per cent—that is, from 22 to 44 per cent tricalcic phosphate. This is owing to the difference in the percentage of phosphorus in the raw material and the quantity of lime added. Attempts have been made in Germany during the last two or three years to obtain a slag richer in phosphoric acid than that obtained heretofore, and a process for this purpose has been patented by Professor Scheibler. This consists of a slight modification in the ordinary process. Instead of treating the pig-iron with an excessive quantity of lime, the amount added is not sufficient to effect the complete dephosphorisation of the iron. The resulting slag is very rich in phosphoric acid, and is correspondingly poor in iron. The

¹ See Appendix, p. 417.

iron is then again treated with fresh lime, and the phosphorus completely removed, while the same lime may be used over again. Such slag forms a very much more concentrated phosphatic manure than the ordinary slag, and is known as *patent phosphate meal*.

A point which not only renders the slag a product of peculiar interest from a chemical point of view, but has a most important bearing on its value as a manure, is the nature of the compound formed by the union of the lime with the phosphoric acid.

In the ordinary so-called raw phosphates, such as bone-meal, bone-ash, coprolites, &c., the lime and phosphoric acid are combined in the form of what is known, in chemical phraseology, as *tribasic phosphate of lime*. That is to say, that for every equivalent of phosphoric acid there are three equivalents of lime. Now it was naturally concluded at first that the tribasic phosphate was the form in which these two substances existed in the slag. This, however, was found out not to be the case, in the following way. On allowing the slag to cool, it was found that small but perfectly defined crystals were formed. These crystals, by careful analysis, were shown, first by Hilgenstock, to consist of a form of phosphate of lime hitherto unknown, in which four equivalents of lime were combined with one equivalent of phosphoric acid, and which was therefore called "*tetrabasic phosphate*."

Processes for preparing Slag.

As soon as the idea of utilising the slag as a manure was suggested, various plans for extracting its phosphoric acid, and rendering it available as plant-food, were devised. These were deemed necessary, it was thought, by the very insoluble nature of the phosphates in the slag, as well as by the supposed injurious action which would be exerted on plant-life by the protoxide of iron it contained. Accordingly, a large number of patents were taken out, "covering almost every conceivable method for treating the slag, whether practicable or not. They all in the main are combinations or variations of the following processes :—

" 1. Preliminary preparation of the Slag.

- (a) By treating molten, or otherwise, with superheated steam, or cooling when hot with water, to reduce it to small pieces or to a fragile state.
- (b) Grinding.
- (c) Treating with water to wash out free lime, or with sugar solution.
- (d) Roasting in the air, or with some oxidising agent.

" 2. Solution of the Slag.

- (a) *Completely* in weak or strong acids (hydrochloric, sulphuric, &c.)
- (b) *Partially*, so as to dissolve the phosphates

and silicates of lime, and leave most of the iron and manganese oxides.

“3. *Precipitation* of the phosphoric acid, with lime or iron salts; or,

“Processes in which the slag is smelted with charcoal, to reduce phosphates to phosphides, treated with acid, and the phosphuretted hydrogen burnt to phosphoric acid; and,

“Processes in which the slag is fused with soda or potash salts,—caustic, chlorides, sulphates, carbonates,—with or without steam being forced through, to form soluble alkaline phosphates.”¹

Many of these processes were tried; but it was found by experiment that the best and most economical way was by applying the slag direct to the ground in a state of very fine powder. Experiments further showed that it had *not* the injurious effect on vegetation which it was feared it would have from the protoxide of iron it contained. The discovery that its phosphoric acid existed, as has been already explained, as a tetrabasic phosphate of lime, has strengthened the opinion that this is the best method of application.

A good deal has been found to depend upon the fineness of the ground slag, with the result that it is now commonly sold on a mechanical as well as a

¹ *Vide* paper on “Basic Slag: Its Formation.” By Stead and Ribsdale. ‘Journal of the Iron and Steel Institute,’ 1887, p. 230.

chemical analysis—*i.e.*, the slag is guaranteed to pass through a sieve of a certain fineness.

Solubility of Slag.

Professor Wagner of Darmstadt has carried out some extremely interesting experiments on the solubility of slag. He found that very finely powdered slag was dissolved in carbonic acid water to the extent of 36 per cent, while, similarly treated, phosphorite only dissolved to the extent of 8 per cent.¹ Another very important solvent is *citrate of ammonia*. Reverted (or precipitated) phosphate is entirely soluble in it, and phosphate soluble in it ought to be valued as worth more than that which is not. Now, the solubility of Thomas-slag in citrate of ammonia was found by Professor Wagner to be no less than 74 per cent, while that of phosphorite only amounted to 4 per cent. These results were corroborated by Professor S. W. Johnson, who found that of the 19.87 per cent of phosphoric acid contained in a sample of basic slag, no less than 19.57 per cent was soluble in ammonium citrate, while a finely ground sample of phosphatic rock yielded, on analysis, only 1.81 per cent soluble in citrate of ammonia, of a total of 29.49 per cent phosphoric acid which it contained. Professor Fleischer has also tested the comparative solubility of basic slag and phosphorite, by boiling

¹ *Vide* Professor Wagner's pamphlet, 'Der Düngewerth und die rationelle Verwendung der Thomas Schlacke,' Darmstadt, 1888.

them in a solution of acetic acid. The former was found to have been dissolved to the extent of 19 per cent, while the latter to only 5 per cent. A highly interesting and most important experiment was performed by Mr Heinrich Albert, of Biebrich. One gramme of basic slag and 100 grammes of peat were mixed together in a litre of water, and it was found that, after standing for fourteen days, 79 per cent of the phosphoric acid contained in the slag was rendered soluble.

In the above experiments it was found that the *fineness of grinding* had a marked effect on the solubility of the slag, and that the finer it was ground the greater was its solubility. This has been further demonstrated in Professor Wagner's practical experiments. From these it was found that finely ground slag has an action *four times* as quick as coarse slag; but that, as far as practical results were concerned, there seemed to be a limit to the fineness to which it was advisable to grind the slag, as slag above a certain fineness did not give better results than a coarser slag. At any rate, he found that slag of a fineness so great that it all passed through a gauze sieve, gave no better results in his experiments than slag which left 17 per cent behind. We may say, however, that the *finer the slag is ground, the greater will its activity as a manure be*; and that a certain degree of fineness is absolutely necessary to constitute it an active fertiliser. As

Professor Wagner's experiments are among the most valuable and complete carried out on basic slag, we shall give a somewhat detailed account of them.

Darmstadt Experiments.

Professor Wagner's experiments were carried out on such different kinds of crops as flax, rape, wheat, rye, barley, peas, and white mustard, and the object of the experiments was to ascertain the comparative activity as fertilisers of superphosphate, basic slag of different degrees of fineness, Peruvian guano, damped bone-meal, and very finely ground coprolites. In order to obtain a correct estimate of the relative value of these different forms of phosphatic manures, it was necessary to render the nitrogen in the bone-meal and the nitrogen and potash contained by the Peruvian guano inactive—*i.e.*, to limit the test strictly to phosphoric acid. This was done by adding to the super, basic slag, and coprolites, quantities of nitrogen and potash equal to those contained by the other manures. There was further added to all the experiments (the unmanured ones, of course, as well) an excess of nitrogen and potash. In this way the increase in returns could only be due to the phosphoric acid.

The general results obtained from these experiments may be summed up as follows: Taking the activity of "super" to be represented by 100, then the relative activity of—

Basic slag of No. 1 ¹ fineness is	.	.	61
Basic slag, No. 2 ²	.	.	58
Peruvian guano	.	.	30
Basic slag, No. 3 ³	.	.	13
Bone-meal	.	.	10
Coprolites	.	.	9

From these results the value of the commercial article has been attempted to be ascertained. As it contains 80 per cent or thereby of fine meal and 20 per cent of coarse, its activity may be stated to be 50, or half as active as super. Thus 2 cwt. of basic slag is equal to 1 cwt. of super. This only refers to the first year's effect. Professor Wagner has made further experiments as to the after-effects of the different manures, with the result that he has found that the after-effects of the basic slag are even *better* than those of the "super." This stands to reason, for if twice as much phosphoric acid be added in the form of basic slag as is added in the form of "super," and the effect of the first year is similar—that is, the same quantity of phosphoric acid is assimilated by the plant from the soil in both cases—there is naturally more phosphoric acid left behind in the soil manured with basic slag than in that manured with superphosphate of lime. For example, if 100 lb. of super has the same effect in the first year as 200 lb.

¹ No. 1 fineness was such as passed entirely through a fine gauze sieve of 250 wires to the linear inch.

² No. 2 fineness was such as passed entirely through the regular standard sieve—*i.e.*, containing 120 wires to the linear inch.

³ No. 3 was what would not pass through the standard sieve.

of basic slag, and it is found that only 60 lb. of the super and the basic slag have been assimilated the first year by the plant, it is only natural to conclude that the remaining 140 lb. of the basic slag will have a better after-effect than the remaining 40 lb. of super. This has been actually proved to have been the case in Professor's Wagner's experiments. The following are the results of some experiments which Professor Wagner has carried out on the after-effects of different manures:—

Out of 100 parts of phosphoric acid, there was removed by the first year's crop—

Super	63
Peruvian guano	22
Bone-meal	7
Coprolites	6
Thomas-meal—	
No. 1 fineness	39
No. 2 "	43
No. 3 "	15

Out of 100 parts of phosphoric acid left by the first crop, there was removed by the three succeeding crops—

Super	30
Peruvian guano	9
Bone-meal	13
Coprolites	6
Thomas-meal—	
No. 1 fineness	14
No. 2 "	29
No. 3 "	24

Numerous other experiments have been carried out

by various experimenters in different parts of Germany which it is unnecessary to cite here. None, however, are so complete as those of Professor Wagner.

Results of other Experiments.

In this country experiments have been carried out at Rothamsted, Cirencester, Downton, Bangor, and by Dr Aitken at the Highland and Agricultural Society's stations, as well as elsewhere. The results of these various experiments naturally differ considerably, this being owing to the difference in the nature of the soils upon which the experiments were carried out, as well as the different degrees of fineness of the slag used. They all, however, serve to confirm Professor Wagner's general results. The results obtained in Scotland by Dr Aitken at the Highland Society's stations were especially favourable to basic slag as a phosphatic manure. The experiments were carried out on turnips, and it was found that the Thomas-slag was, weight for weight, superior to superphosphate. It may be added that the slag used in these experiments was rich in phosphoric acid, and was in an unusually fine state of division. Experiments carried out by the author have proved slag to be, on various Scottish soils, one of the most economical phosphatic manures to apply to turnips.¹

We will sum up, in conclusion, the deductions

¹ 'Transactions of the Highland and Agricultural Society,' 1891 ;
'Chemical News,' 1893.

which may be fairly drawn from the results of all the above-mentioned experiments as to the value of basic cinder as a manure.

Soils most suited for Slag.

Although its action is undoubtedly more favourable on some soils than others, it may be broadly stated that generally its phosphoric acid is *half as valuable* as that in soluble phosphate. The soils on which it will have the most marked effect will be those of a *peaty* nature, *poor* in lime, but *rich* in *organic matter*. The beneficial results obtained by an application of lime to peaty soils are well known. As the slag contains a large percentage of free lime, it thus performs on such soils a double function. On meadow-lands, all kinds of pasture-lands (if not of too dry a character), and clay soils poor in lime, its action has been shown to be especially favourable. Of different kinds of crops, those best suited to benefit from the slag as a phosphatic manure are those of the leguminous kind. This arises from the fact that their period of growth is longer than that of most other crops.

Rate of Application.

As to the rate per acre at which the slag ought to be applied, there will naturally be a difference of opinion. Professor Wrightson, of Downton Agricultural College, recommends that it should be applied at the rate of from 6 to 10 cwt. per acre. This, of course, is very

liberal manuring. We must remember, however, that phosphatic manures, unlike nitrogenous manures, and to some extent potash manures, may be applied in even excessive quantities without any risk of loss. It is impossible to measure out our phosphate manures in the same accurate manner as we measure out our nitrogen. It is safer, therefore, and on that account more economical in the long-run, to apply our phosphate in excessive quantity than the reverse. The reason of this may be shortly explained. The phosphoric acid which is naturally present in most soils is with difficulty soluble. Only a small quantity is yielded daily to the plant. This quantity may, under favourable climatic conditions, be sufficient; but these favourable influences never last very long at a time.

For three weeks, perhaps, the plant may experience drought, and during this period it takes up no phosphoric acid, and its growth practically comes to a standstill; but this period of drought is followed by rain and warm weather, and the plant, if it is to be ripe by harvest-time, must make up for lost time. It must grow as much the next few days under these favourable climatic conditions as it would have grown under normal conditions in double or treble the time. In order to do so, however, it must be able to obtain plenty of phosphoric acid, and this is only possible where there is a decided excess of phosphoric acid present in the soil.

The richness of a soil, therefore, in phosphoric acid,

must be such that it is not only able to supply the ordinary wants of the plant, but to provide an excess when such an excess will be needed; for one must remember that the amount of plant-substance formed in the course of a few days under favourable conditions is very great, and that the amount consequently of phosphoric acid which plants assimilate during that period must also be very considerable.

Method of Application.

In conclusion, as to the method of application of the slag, agriculturists must be *warned against mixing it with sulphate of ammonia*; for if this is done, a *considerable loss of ammonia* will ensue, set free from the sulphate by the action of the free lime which the Thomas-slag contains. With nitrate of soda, and potash salts it may be freely mixed. Such mixtures, however, are apt to form themselves into little balls, which soon become very hard. They should therefore only be mixed shortly before use. To overcome this difficulty, Professor Wagner recommends the mixture of a little peat or sawdust with the slag.

APPENDIX TO CHAPTER XIV.

NOTE (p. 404).

For those more particularly interested, we append a full analysis of the slag, taken from Messrs Stead and Ribsdale's paper in the 'Journal of the Iron and Steel Institute,' 1887, vol. i. p. 222 :—

Lime	41.58
Magnesia	6.14
Alumina	2.57
Peroxide of iron	8.54
Protoxide of iron	13.62
Protoxide of manganese	3.79
Protoxide of vanadium	1.29
Silica	7.38
Sulphur } . . . . .	.23
Calcium } . . . . .	.31
Sulphuric anhydride . . . . .	.12
Phosphoric acid	14.36
	<hr/>
	99.93

CHAPTER XV.

POTASSIC MANURES.

Relative Importance.

IN Chapter VI. we pointed out that of the three manurial ingredients potash was the one most abundantly occurring, and that, consequently, the necessity of adding it in the form of an artificial manure existed less frequently than in the case of nitrogen or phosphoric acid. It was further pointed out that, under the ordinary conditions of agriculture, a greater restoration to the soil of the potash removed in the crops was made in the straw used in farmyard manure than was the case with regard to the other two ingredients. Despite these facts, there are many cases where the addition of potassic manures is of the highest importance in increasing plant-growth. It will be well, therefore, to devote a little space to considering our different potassic manures and their respective action.

Scottish Soils supplied with Potash.

Potassic manures are not so valuable in this country since experience has shown that most Scottish soils are abundantly supplied with this manurial ingredient. Moreover, under the conditions of most European farming, there seems to be a steady gain to the soil of potash. In America, however, the action of potash as a manure seems to be more strikingly illustrated. Indeed, wherever forage crops or straw are sold off the farm in large quantities, or where beets, cabbages, carrots, potatoes, onions, &c., are also grown in large quantities, the necessity for potash manuring generally arises.

Sources of Potassic Manures.

The value of potash as a manure first came to be recognised from the favourable action of wood-ashes. Of course their favourable action is not due solely to potash, as they contain, in addition to the other ash ingredients of the plant, phosphates; and their value as a manure may also be said to depend not a little on their indirect action. They contain a certain percentage of caustic alkali, which promotes the decomposition of the nitrogenous matter of the soil. But making due allowance for these other valuable properties, the chief value of wood-ashes is undoubtedly due to the potash they contain. Hence the use of the commercial article called *potash*, which is a

mixture of potassium carbonate and hydrate, and which is obtained from wood-ashes, was formerly common to a considerable extent as a manure, especially for clover. *Barilla*, a rich potassic manure prepared by burning certain strand plants, especially the saltwort, was also in the past largely exported from Sicily and Spain. *Kelp*, a product got by burning sea-weed in Scotland, is also a rich potassic manure. Since, however, the discovery of the Stassfurt mines, all potassic manures have come from these.

Stassfurt Potash Salts.

Huge salt deposits exist at Stassfurt in Germany. They have been formed by the evaporation of an inland sea. Salt was first discovered in these deposits in 1839, but for long the presence of potash salts was little suspected, and it was not until 1862 that the potash salts were worked. We have already, in the Appendix to Chapter VI., given a list of the chief potash minerals occurring in the Stassfurt deposits. These minerals are found in layers, the lowest layer consisting of almost pure salt; while immediately above this we have a layer of salt mixed with the mineral polyhallite (containing potassium sulphate) of about 100 feet thick. Above this last layer there is a layer of about 90 feet, containing kieserite (magnesium sulphate) mixed with potassium and magnesium chlorides; and above this again is a layer (90 feet) of carnallite, which furnishes the

chief source of the potash salts used for manurial purposes.

At first the crude salts, as obtained direct from the deposits, were sold as manures under the name of *Abraum* salts. Now, however, they are purified. Of potash salts in 1888 some 25,000 tons were exported from Stassfurt for manurial purposes. Of these salts there may be mentioned, viz., kainit, an impure form of the sulphate, containing on an average about 12 per cent of potash, and the muriate and the sulphate—both salts, in a more or less pure form, being used. A word or two may be added on the effect of the two forms of potash—viz., as the sulphate and as the muriate.

Relative Merits of Sulphate and Muriate of Potash.

It is a well-known fact that muriate of potash, far from having a beneficial effect on certain crops, is actually harmful. Of these, sugar-beets, potatoes, and tobacco may be mentioned. In the case of beets it seems to have an effect in lessening the percentage of crystallisable sugar, while potatoes are rendered waxy. With regard to the tobacco-plant, it seems to impair the value of the leaf from the smoker's point of view. That this deleterious action is due to the form in which the potash is present, and not to the potash itself, seems to be pretty clear, since potash in the form of sulphate has not this deleterious effect on these plants. Another objection which has been urged against muriate of potash is that, when applied as a

manure, it is apt to give rise to the formation of calcium chloride,—a compound which is distinctly hurtful to many plants. A similar charge cannot be brought against sulphate of potash, since gypsum, which is the chief compound it is likely to give rise to, is of much value, as we have already pointed out, as an indirect manure. On the whole, therefore, sulphate of potash seems to be the safest form in which to add potash. Unfortunately, however, most of the commercial sulphates are very impure, and contain generally considerable quantities of muriate. In favour of the muriate, it may be said that it is the more concentrated manure, and that it diffuses better in the soil than the sulphate—a point of great importance. It has, moreover, been used without any bad effect for clover, corn, grass, and some root crops.

Application of Potash Manures.

The extreme tenacity with which the soil-particles fix potash salts, when applied as manures, is a point which ought to be borne in mind in their application. This, as we have just noticed, is greater in the case of the sulphate than in the case of muriate, and it has been observed that certain other fertilisers seem to exercise a considerable influence in hindering their fixation. Among these may be mentioned bone-meal and farmyard manure. Nitrate of soda also seems to increase the diffusibility of potash salts. Conversely, potash salts seem to help to fix ammonia.

For the above reasons potash manures ought to be applied to the soil a considerable period before they are likely to be used by the crop. There is little risk of any serious loss taking place owing to rain. Autumn application is generally recommended. Even in very light soils it has been proved in the Norfolk experiments that autumn application has an immense advantage over spring application. It has been found that where potash is applied as sulphate, little sulphuric acid is absorbed by the plant.

Soils and Crops suited for Potash Manures.

Of soils best suited for potash manures, it has been found that light soils, and those largely charged with peaty organic matter (such as the moorland soils of Germany), are most benefited; while on heavy clayey soils the percentage of potash which these latter contain is already sufficiently abundant for the needs of plants. At Fritcham the value of potash on chalk soils has been strikingly demonstrated. Of crops, it is now pretty generally acknowledged that those of the leguminous order are most benefited by potash. Especially in the case of clover has potash always proved itself a manure worth applying.

Rate of Application.

Potash is best applied in small quantities. From 1 to 2 cwt. of the muriate or sulphate is a common amount, and from 6 to 8 cwt. of kainit.

CHAPTER XVI.

MINOR ARTIFICIAL MANURES.

IN addition to the manures which have been discussed in previous chapters, there are a number of minor manures which are used to a very much smaller extent—dried blood, hoofs, horns, &c.

Among these one of the most valuable is dried blood. Fresh blood, containing 80 per cent of water, has from 2.5 to 3 per cent of nitrogen, about .25 per cent of phosphoric acid, and about .5 per cent of alkalies. When dried it forms a very concentrated and valuable nitrogenous manure, which has long been used in France. The commercial article contains, on an average, about 12 per cent of nitrogen, and slightly over 1 per cent of phosphoric acid. When mixed with the soil it ferments, and the nitrogen it contains is converted into ammonia. Although not so quick-acting a manure as nitrate of soda or sulphate of ammonia, it can by no means be described, as is done in ordinary agricultural text-books, as a slow-acting

manure. Its nitrogen may be regarded as of equal value to that in Peruvian guano. It is peculiarly suited for horticulture, and is chiefly used in this country as a manure for hops. It has also been used with beneficial results for wheat, grass, and turnips. As a manure it is best suited for sandy or loamy soils. Considerable quantities are exported to the sugar-growing colonies as a manure for sugar-cane. Manures are made from other animal refuse. It may be mentioned that lean flesh (containing 75 per cent of water) has about 3 to 4 per cent of nitrogen, .5 per cent of alkalies, and .5 per cent of phosphoric acid; that is to say, a ton of lean flesh would contain about 70 lb. of nitrogen and 10 lb. of phosphoric acid. In air-dried flesh, according to Payen and Boussingault (containing $8\frac{1}{2}$ per cent of moisture), there is 13 per cent of nitrogen. Flesh, therefore, is, when properly composted, a valuable nitrogenous manure. Dried flesh is generally made into a manure called meat-meal guano, the composition of which we have already referred to in the chapter on Guano.¹

Hoofs, horns, hair, bristles, and wool, wool-waste and the intestines of animals, have been used as manures. Hoofs and horns form a regular source of artificial nitrogenous manure; the latter being obtained as a bye-product in the manufacture of combs and other articles. They are in the form of a fine powder; and in order to increase their rate of action, which is very

¹ See p. 324.

slow, they are often composted in America with horse-manure before use. They have also been composted with slaked lime. There can be no doubt that such treatment increases very considerably their value. Their percentage of nitrogen seems to vary very much according to the kind of animal from which they are derived. In nine samples of horn the nitrogen was found to vary from $7\frac{1}{2}$ to $14\frac{1}{4}$ per cent; giving an average of $11\frac{1}{3}$ per cent. The nitrogen seems rarely to exceed 15 per cent. The amount of phosphoric acid they contain has been found by various investigators to range from 6 to 10 per cent. S. W. Johnson found only from .08 to .15 per cent in buffalo-horn shavings. In France what is known as "torrefied" horn has been used. This is horn which has been subjected to the action of steam. The nitrogen in this material is considered to be more active than in ordinary horn. According to Way, horns have been used for the hop crop with good results. Ground hoof is very similar in composition to horn, and contains about 14 to 15 per cent of nitrogen. Considerable quantities are now used. It must be remembered, however, that horns, hoofs, hair, bristles, &c., although rich in nitrogen, possess a comparatively low manurial value. The home production of these articles may be estimated at 6000 to 7000 tons.

Scutch.

Scutch is the name given to a manure made from the waste products incidental to the manufacture of glue and the dressing of skins. It contains about 7 per cent of nitrogen, and is manufactured in London to the extent of several thousand tons annually.

Shoddy and Wool-waste.

Shoddy, which is a manure made from waste-wool products, is a material largely manufactured in this country, and which was formerly (it is now used to a considerably less extent) used to a large extent as a manure. Its annual production amounts to about 12,000 tons. There are three qualities,—the first containing 8 to 12 per cent of nitrogen; the second, 6 to 8 per cent; and the third, 5 to 8 per cent. Shoddy is by no means a very valuable manure. Woollen-waste products were formerly much richer in nitrogen than is now the case. This is due to the fact of the adulteration with cotton, now so prevalent in the manufacture of woollen goods. Pure woollen rags should contain 17 to 18 per cent of nitrogen. It has been strongly recommended to treat woollen waste with caustic alkali before being used as a manure, in order to render their nitrogen more quickly available; and there is a good deal to recommend this treatment. When wool-waste is applied as a manure, it should in

every case be in autumn, so as to allow as long a period as possible to elapse before it is required for the plant's growth.

Leather has also been used as a manure. Its nitrogen may be stated at from 4 to 6 per cent; and it may safely be described as of all materials used as nitrogenous manures the least valuable. Leather is, from its very nature, admirably adapted to resist decomposition when applied to the soil, and unless it is reduced to a very fine condition, might be trusted to remain undecomposed for a long period. Torrefied leather; however, is probably of greater value. It is obtained in the same way as torrefied horn, already referred to—namely, by treatment with steam. The grease and fatty matters which so largely aid it in resisting decomposition being extracted, it is much better suited for manurial purposes than ordinary leather. Torrefied leather contains from 5 to 8 per cent of nitrogen.

Soot.

A manure which has long been used and highly esteemed is soot. Obtained in the usual way, it generally contains some 3 per cent of nitrogen, chiefly in the form of sulphate of ammonia, and small quantities of potash and phosphates. A varying proportion of the nitrogen is present in the form of ammonia salts; and this undoubtedly confers upon soot its manurial value. It has long been used as a top-

dressing for young grain and grass, and has been applied at the rate of from 40 to 60 bushels per acre. It has an indirect value as a slug-destroyer.

Many of the above-mentioned manures, of comparatively low value, will probably be less used in the future than they have been in the past, owing to the more abundant supplies of nitrate of soda and ammonia salts which are now available. Many of these substances have probably been used in mixed manures.

CHAPTER XVII.

SEWAGE AS A MANURE.

THE value of sewage as a manure has been in the past enormously overrated, and much misunderstanding has existed on the part of the public on the question of the profitableness of the disposal of town sewage as an agricultural manure. Not a few of the erroneous opinions prevalent in the past regarding sewage have been due to statements made by scientific and other writers as to the enormous wealth lost to the world by many of the present methods of sewage disposal. Fortunately, however, the sewage question is now increasingly regarded as a question, in the first instance, of sanitary interest. As much has been written on the subject, and many schemes have been devised, at the expense of much ingenuity, for utilising its manurial properties, it may be desirable here to say a few words on the purely agricultural side of the question.

The two most important points about sewage are its enormous abundance and its extremely poor quality.

If the most important consideration were not the sanitary one, but its manurial value, then indeed our water system, so universally used in towns, must be regarded as a most wasteful one; for by its means the value of the excrementitious matter from which it derives its manurial ingredients is tremendously lessened. When we reflect that a ton of sewage, such as is produced in many European cities, contains only 2 or 3 lb. of dry matter, and that the total amount of nitrogen in this is only an ounce or two, while the phosphoric acid is considerably less, and that it is on those two ingredients that its value as a manure entirely depends, we see very strikingly how poor a manurial substance sewage is. Various methods have been devised and experimented with for extracting these manurial ingredients, and many methods are in operation in different parts of the world. The methods of utilising sewage for agricultural purposes may be broadly divided into two classes.

Irrigation.

One of these, which may be classed under the heading of irrigation, consists in pouring the sewage on to certain kinds of coarse green crops. Sometimes the land is made to filter large quantities of sewage by special arrangements of drains and ditches. The land is first carefully and evenly graded down a gentle incline. At the top of the field the sewage is conducted along an open ditch from which it is permitted to escape, by the

force of gravity, by several smaller ditches running at right angles from the main ditch. By means of stops which may be shifted at will, the sewage can be directed to flow over different parts of the field. Modifications in this plan may be made so as to suit the nature of the ground. In the case, for example, of a steep incline, the field may be sewaged by means of what are known as "catch-work" trenches running horizontally along the hill. In this way the sewage is allowed to pass over the whole of the field, and is caught at the bottom in a deep ditch, whence it is allowed to flow into the nearest river or stream. This is the system which has been employed at the famous Beddington Meadows, near Croydon.

Another method of distributing the sewage is by means of underground pipes, which are laid in a sort of network over the ground to be manured. At certain intervals pipes with couplings for hose are fitted on, and by keeping a certain amount of pressure on the main pipes the sewage may be distributed over the different parts of the field as it is required.

A third modification is subsoil irrigation. This resembles the last-named system, with this difference, that the pipes used are either porous or perforated with small holes.

Total submersion can only be applied in the case of absolutely level lands, and is practised to an enormous extent in Piedmont and Lombardy.

There has been little dispute as to the thorough

efficiency of irrigation—when conducted under favourable conditions—as a method of purifying sewage and utilising to the full its constituents of manurial value. It is the only method which has been conclusively shown to extract from sewage that to which it owes most largely its value as a manure—viz., ammonia; and from this fact it deserves a first place in the consideration of agriculturists. For however admirable other methods may be from a sanitary point of view, it is obvious that a method which would allow the ammonia in sewage wholly, or at least to over 90 per cent, to be lost, cannot claim the same place in the judgment of agriculturists as a method which can extract for the soil not only the whole of this valuable constituent, but all else in the sewage which in any way is of value to plant-life.

Effects of continued Application of Sewage.

When sewage is continuously applied to the same land, what generally takes place is this: At first the sewage is purified, and the soil derives corresponding benefit from the valuable fertilising ingredients it thus extracts. After a time, however, the land becomes what has been termed “sewage-sick.” The pores in the soil become choked up by the slimy matter the sewage contains in suspension; the aeration of the soil, which, as we have already mentioned, is so necessary, is consequently to a large extent stopped; and the result is, that the land rapidly deteriorates, and the sewage is no longer purified.

Intermittent Irrigation.

This is obviated to some extent by intermittent irrigation. The land, instead of receiving sewage continuously, only receives it at intervals, and is allowed some time to recover between each dose. It is, however, the opinion of those who have given the subject much attention, that land, even although intermittently sewaged, never recovers its original efficacy.

Irrigation, therefore, under favourable conditions, is a most successful method of utilising the manurial value of sewage; but the great difficulty in practice is to obtain those favourable conditions. It has long been known that if soil is properly to discharge its function as a purifier of sewage water, it must be properly aerated; and we now know that in every fertile soil the process of nitrification must be permitted free development. Now the application of large quantities of sewage to a soil is apt to prevent this free development. As we have already seen, absence of air and the lowering of the temperature of the soil distinctly tend to retard nitrification; and these two conditions accompany the application of large quantities of sewage.

Crops suited for Sewage.

Another objection to irrigation has been found in the alleged limited number of crops sewaged land is suited to yield. It has been repeatedly stated that rye-grass is about the only crop it is profitable to grow

on it. In opposition to this statement, however, is the opinion expressed in the conclusions arrived at by the committee appointed by the British Association for the consideration of the sewage question. A vast number of experiments were carried out by them between the years 1868-72, and the result they arrived at was as follows: "It is certain that all kinds of crops may be grown with sewage, so that the farmer can grow such as he can best sell; nevertheless, the staple crops must be cattle food, such as grass, roots, &c., with occasional crops of kitchen vegetables and of corn." While, therefore, it is probably a mistake to say that rye-grass is the only crop sewage land is capable of growing profitably, the bulk of experience goes to show that such a crop is best suited for such land. This being so, the question naturally arises, What is the farmer who uses sewage as a manure to do with the large green crops he obtains from his land? He is, in most cases, unable to use them himself or dispose of them at the time. And while this has hitherto proved to be a most important drawback, now that we have in ensilage a means of preserving our green crops in a condition suitable as fodder for as long a time as is necessary, the grounds on which this objection rests are almost entirely removed.

It will be obvious, of course, that some soils are naturally much better fitted to perform purification of sewage than others; but it must be frankly admitted that even the best of soils can only deal with a certain

quantity of sewage. Various calculations have been indulged in as to the amount of sewage an acre of land can successfully deal with. According to one of these, an acre can purify some 2000 gallons per day, or that produced by 100 persons; while other calculations estimate it at 60 persons; and others, again, at 150. The capacity of a sandy soil in this respect will be much greater than that of a heavier soil; and at Dantzic an acre of the sand-dunes is regarded as being capable of purifying the sewage of 600 persons. The late Dr Wallace has calculated that, in order to treat the sewage of Glasgow, over twelve square miles of land would be required. Of course, if the sewage is subjected to previous treatment, which is often the case, by the method immediately about to be described—namely, precipitation—the amount of sewage the soil is capable of purifying will be correspondingly increased. A difficulty which may also be pointed out in connection with irrigation as a means of disposing of sewage, is the impossibility of carrying it on during frosty weather, when the land is frost-bound. In warm climates irrigation has much to recommend it as a means of sewage disposal. In damp and cold climates, on the other hand, there are many objections.

Treatment of Sewage by Precipitation, &c.

We now come to consider the methods grouped under this second heading. Mechanical filtration, of course, only aims at purifying sewage to the extent of

removing all insoluble suspended matter which it contains. Different substances have been used as filters, the most generally used being charcoal. Charcoal mixed with burnt clay, gravel, sand, &c., has also been used.

In chemical precipitation, however, we have a method which claims to do more. Beyond the extracting of all solid matters in suspension, it removes (at any rate most chemical precipitants do) nearly all the phosphoric acid, which, next to the ammonia, is the most valuable constituent the sewage contains. Of all precipitants, lime has been the most universally used; and on the whole, it is perhaps the best, for it is both cheap and obtainable almost anywhere. According to an analysis by the late Professor Way, the difference in the percentages of phosphoric acid, potash, and ammonia, before and after treatment with lime, in a sample of sewage, was as follows:—

Grains per Gallon.

			Before.	After.
Phosphoric acid	.	.	2.63	.45
Potash .	.	.	3.66	3.80
Ammonia .	.	.	7.48	7.50

From the above we see that while sludge caused by lime as a precipitant contains nearly all the phosphoric acid, there is not a trace of the potash or ammonia removed. Sulphate of alumina has also been used, both alone and in conjunction with lime. The advantage claimed by it over lime is, that the resulting

precipitate is much less bulky. In other respects, however, it does not seem to be any more efficient as a precipitant. In the well-known A, B, C process, a mixture of alum, clay, lime, charcoal, blood, and alkaline salts, in different proportions, has been used. This mixture is said to extract, in addition to the phosphoric acid, a certain proportion of the ammonia; but the amount is so small as scarcely to be worth considering.

Numerous other chemical substances have been used, alone and also in conjunction with one another, such as perchloride of iron, copperas, manganese, &c. All alike, however, have failed to do more than effect partial purification,—the best results, it may be added, being obtained when the sewage thus treated was fresh. With regard to the manurial value of the resulting sludges, much difference of opinion has existed. The small percentage of phosphoric acid and nitrogen they contain has prevented them from being used to any extent as a manure, as their value did not admit of carriage beyond the distance of a few miles. By the introduction a few years ago of the filter-press, their value has been considerably enhanced. The old method of dealing with the sludge at precipitation-works was to allow it to dry gradually by exposure to the atmosphere. The result, however, of leaving sewage-sludge with over 90 per cent of water in it to dry in the air, was to encourage the rapid decomposition and putrefaction of its organic

matter, so that in many cases the decomposing sludge proved to be as great a nuisance as the unpurified sewage itself would have been. By the use of Johnson's filter-press, however, a sludge containing 90 per cent of water was at once reduced to 50 per cent, or even less. By this means the percentage of its valuable constituents was very much increased, and the sludge-cake, besides being much more portable, was neither so objectionable nor so liable to decomposition as before.

Value of Sewage-sludge.

As to the value of this sludge-cake as a manure, we are happily in possession of some very interesting and valuable experiments by Professor Munro of Downton Agricultural College. The sludge experimented upon was that produced by sulphate of alumina, lime, and sulphate of iron, and contained, after being subjected to Johnson's filter-press, from .6 to .9 per cent of nitrogen, and over 1 per cent of phosphoric acid. It was found that the benefit resulting from the application of the sludge was far from what in theory might have been expected. The experiments were made with turnips; and the results obtained with superphosphate and farmyard manure respectively, in the same field and under exactly the same conditions, were contrasted with those obtained with sludge. Thus it was found that 53 lb. of phosphoric acid as superphosphate, or 60 lb. as farmyard

manure, produced a considerably larger crop than 240 lb. of phosphoric acid in the sludge. That is to say, that the phosphoric acid in the sludge did not exert more than one-fifth of its theoretical effect. The explanation of this somewhat strange result Dr Munro finds in the unsuitable physical character of the sludge-cakes. In farmyard manure we have a loose texture and a large amount of soluble constituents when well rotted. It thus quickly distributes its fertilising elements throughout the soil. In the case of the sludge, on the other hand, its composing particles are closely compacted together, and thus offer the greatest resistance to mechanical and chemical disintegration. "As a matter of fact," says Dr Munro, "the sludge-plots in my experimental series were all readily identified, when the roots were pulled, by the presence of unbroken and undecomposed clods of cake, which had evidently given up, at most, a small portion of their valuable ingredients to the soil."

Briefly stated, therefore, the objections to chemical precipitation as a means of dealing with sewage are these—viz., that while it relieves sewage of all its organic matter, and to a large extent of its phosphoric acid, it fails to extract any ammonia, which is thus lost; that the resulting sludge is consequently so poor in fertilising matters as scarcely to make it worth while to remove it any distance for manuring purposes; and that, further, owing to its unfavourable

physical character, as at present made, even the small percentage of plant-food it contains is not realisable, within, at any rate, anything like a reasonable time, to its full theoretical extent.

The most profitable method of treating sewage must be determined by various local conditions; and it must be clearly understood that the question of sewage disposal is primarily a sanitary one, and that it must be dealt with from the sanitary aspect. The most profitable way of applying sewage as a manure, however, will doubtless be found by combining chemical precipitation and land irrigation.

CHAPTER XVIII.

LIQUID MANURE.

THE adoption of irrigation as a means of utilising sewage, suggests a short consideration of the value of liquid manures. It has been a custom on many farms to apply the liquid manure got from the oozings of manure-heaps, the drainings of the farmyard, byres, stables, piggeries, &c., directly to the soil. Indeed, so strongly has the belief in the superiority of liquid manure over other manure been held by certain farmers, that they have washed the solid animal excreta with water, in order to extract from it its soluble fertilising constituents. The late Mr Mechi was one of the foremost exponents of the value of liquid manure. His farm of Tiptree Hall was fitted up with iron pipes for the distribution of the manure over the different fields. Superphosphate, it may also be added, as first made from bones by Baron Liebig, was applied in a liquid form. As to the general merits

of liquid manure, there can be no doubt that it is the most valuable form in which to apply manure. It secures for the manurial ingredients it contains a speedy and uniform diffusion in the soil; but, on the other hand, the expense of distributing it makes its application far from economical. The chief ingredient in liquid manure is urine. Now the removal of urine from the farmyard manure-heap entails a severe loss of the ingredient which is most potent in promoting fermentation. Separation of the urine from the solid excreta is on this very account not to be recommended. Urine, when applied alone, is lacking in phosphoric acid, of which it contains mere traces. It is not, therefore, suitable as a general manure. It has to be pointed out, however, that the drainings from a manure-heap in this respect are superior to pure urine, since they contain the soluble phosphates washed out of the solid excreta. The objections against using liquid manure may be summed up as follows:—

First, it is too bulky a form in which to apply the manure, and hence too expensive; secondly, it is not advisable to deprive the solid excreta of the liquid excreta, as the one supplements the other; thirdly, fermentation is largely fostered in the solid excreta by the presence of the liquid excreta—hence fermentation will not take place properly in the solid excreta when deprived of the liquid excreta.

If, however, the production of liquid manure on the

farm is in excess of what can be used for the proper fermentation of farmyard manure, it will be best to utilise it for composts. No better addition to a compost can be made than liquid manure, as it induces speedy fermentation in nearly all kinds of organic matter.

CHAPTER XIX.

COMPOSTS.

THE use of composts is an old one. Before artificial manures were so plentiful as they are at present, much attention was paid by farmers to their preparation. A compost is generally made by mixing some substance of animal origin which is rich in manurial ingredients with peat or loam, and often along with lime, alkali salts, common salt, and indeed any sort of refuse which may be regarded as possessing a manurial value. Composting, in short, may be looked upon as a useful method of turning to profitable use refuse of various kinds which accumulate on the farm. The object of composting is to promote fermentation of the materials forming the compost, and to convert the manurial ingredients they contain into an available condition for plant needs. Composts often serve a useful purpose in retaining valuable volatile manurial ingredients, such as ammonia, formed in easily fermentable substances like urine. In fact,

we may say that farmyard manure is the typical compost, and its manufacture serves to illustrate the principles of composting.

Farmyard Manure a typical Compost.

Farmyard manure as ordinarily made is not generally regarded as a compost, but in the past it has been widely used for the purpose of making composts. Thus the practice of mixing farmyard manure with large quantities of peat has been in some parts of the world a common one. Peat, as has already been pointed out in a previous chapter, is comparatively rich in nitrogen. When it is mixed with urine or some other putrescible substance, the peat undergoes fermentation, with the result that its nitrogen is to a greater or less extent converted into ammonia. The effect, therefore, of mixing peat with farmyard manure is beneficial to both substances mixed: the escape of ammonia is rendered impossible by the fixing properties of the peat, while the inert nitrogen of the peat is largely converted by fermentation into an available form. The proportion of peat which it is advisable to add in composting farmyard manure will depend on the richness of the quality of the manure: the richer the quality of the manure, the greater the amount of peat it will be able to ferment. Composts of this kind are generally made by piling up the manure in heaps, consisting of alternate layers of peat and farmyard manure. From one to five parts of peat to every

one part of farmyard manure is a common proportion. The use of such a manure, containing so much organic matter, will exercise its best effect on light sandy soils.

Other Composts.

But instead of farmyard manure, or in addition to farmyard manure, various other substances may be added, as bones, flesh, fish-scrap, and the offal of slaughter-houses. Sometimes leaves and the dried bracken-fern are used for the manufacture of composts. Some of these substances contain much nitrogen or phosphoric acid, but in their natural condition ferment when applied to the soil at a slow rate. If mixed together before application in pits with peat, leaves, bracken-fern, or some other absorbent material, fermentation proceeds evenly and rapidly. The addition of lime, potash, and soda salts has been found to have a most beneficial effect in promoting fermentation. These substances, as is well known, hasten putrefaction of organic matter. Lime seems especially to be valuable in composting. This is no doubt due to the fact that lime plays a valuable part in promoting the action of various ferments, as has already been illustrated in the case of nitrification. The effect of large quantities of sour organic acids (humic and ulmic), which are the invariable products of the decomposition of organic matter like peat, leaves, &c., is inimical to micro-organic life. The action of lime is

to neutralise these acids. There can be no doubt that composting is a useful process for increasing the fertilising properties of different more or less inert manurial substances. But in view of the abundant supply of concentrated fertilisers, the use of composts may considerably decrease in future.

CHAPTER XX.

INDIRECT MANURES.

LIME.

WE now come to discuss those manures which we may class under the term *Indirect*, because their value is due, not to their direct action as suppliers of plant-food—like those manures we have hitherto been engaged in discussing—but to their indirect action. Of these by far the most important is lime.

Antiquity of Lime as a Manure.

Lime is one of the oldest and one of the most popular of all manures. It is mentioned, and its wonderful action commented on, in the works of several ancient writers, more especially Pliny. Of late years, perhaps, its use has become restricted; and, as we shall point out by-and-by, it is well that it is so.

Action of Lime not thoroughly understood.

Despite the fact of the long-established and almost

universal use of lime, it can scarcely be said that we as yet clearly understand the exact nature of its action. Much light, however, has been thrown of late years on the subject by the great advance which has been made in our knowledge of agricultural chemistry. Nevertheless, there are many points connected with the action of lime on the soil which are still obscure. Perhaps one reason for the conflicting ideas prevalent with regard to the value of this substance in agriculture is to be found in the fact that it acts in such a number of different ways, and that the nature of the changes it gives rise to in the soil is most complicated. The experience of agriculturists with lime in one part of the country often seems contradictory to the experience of those in other parts of the country. Its action on different soils is very dissimilar. For these reasons, therefore, the discussion of the value of lime as a manure is by no means an easy one.

Lime a necessary Plant-food.

Lime, as we have already pointed out in a former chapter, is a necessary plant-food, and were it present in the soil to a less extent than is actually the case, would be just as valuable a manure as the different nitrogenous and phosphatic manures; and in certain circumstances this is the case. There are soils, though they are by no means of common occurrence, which actually lack sufficient lime for supporting plant-

growth, and to which its addition directly promotes the growth of the crop. Poor sandy soils are often of this nature. Another class of soils are also apt to be lacking in lime—at any rate their surface-soil is. These are permanent pasture-soils. Originally there may have been an abundance of lime in the surface portion of the soil; but, as is well known to every practical farmer, lime has a tendency to sink down in the soil. This tendency in ordinary arable soils is largely counteracted by ordinary tillage operations, such as ploughing, &c., by means of which the lime is again brought to the surface. In permanent pasture-soils, however, no such counteracting action takes place, hence impoverishment of the surface-soil in lime eventually results. It is for this reason—partly at any rate—that permanent pasture benefits in an especial degree by the application of lime. We say *partly*, for there are other important reasons. One is, that lime seems to have a striking effect in improving the quality of pastures by inducing the finer grasses to predominate. It has also a very favourable action in promoting the growth of white clover. Another reason for the favourable effect of lime on pasture-soils is doubtless on account of the action it has in setting potash free from its compounds. Soils, however, which directly benefit from the application of lime in the same way as they benefit from the application of nitrogenous manures, may be safely said to be rare. In the great majority of soils lime

exists, so far as the demands of plant-life are concerned, in superabundance.

Lime of abundant Occurrence.

Indeed limestone is one of the most abundant of all rock substances, and it has been calculated that it forms not less than one-sixth of the rock-mass of the earth's crust. Nearly all the commonly occurring minerals contain it, and in the course of their disintegration furnish it to the soil. Vast tracts of country are composed of nothing but limestone; and we have examples, even in this country, of so-called chalk-soils, where it is the most abundant constituent. Nor can it be classed amongst the insoluble mineral constituents of the soil; for although insoluble in pure water, it is soluble in water—such as the soil-water—which contains carbonic acid. This is proved by the fact that it is the chief dissolved mineral ingredient in all natural waters.

Lime returned to the Soil in ordinary Agricultural Practice.

It may be further pointed out, as bearing upon the true function of lime when applied as a manure, that in ordinary agricultural practice nearly all the lime removed from the soil in crops finds its way back again to the farm in the straw of the farmyard manure. For these reasons, then, it is clear that the true function of lime is as an indirect manure.

Let us now proceed to discuss its action. Before doing so, however, it is important that we should clearly understand the different chemical forms in which it occurs.

Different Forms of Lime.

Lime occurs chiefly as carbonate of lime in the forms of limestone, marble, or chalk, which are all chemically the same. It occurs also as sulphate of lime or gypsum, as well as in the forms of phosphate and fluoride. In agriculture it is only used—if we except the phosphate, which is applied not on account of its lime, but its phosphoric acid—in the form of the carbonate or *mild* lime as it is commonly called, burnt, caustic, or quick lime, and as gypsum. As the value of gypsum as a manure is of such importance, and depends not entirely on its being a compound of lime, we shall consider it by itself. Hence we have only to consider here the action of mild and caustic lime.

Caustic Lime.

When limestone or mild lime is submitted to a great heat, such as is practically done on a large scale in lime-kilns, it is converted into caustic lime or lime proper. Limestone is made up, as we have just mentioned, of lime and carbonic acid. The latter ingredient is expelled in the form of a gas, and the lime is left behind. Lime never occurs naturally as caustic lime, for the simple reason that it is impossible for

it to remain in this state, owing to the great affinity it has both for water and carbonic acid.

When lime is burnt, and before it is applied to the field, some time is allowed to elapse in order to permit of its absorbing moisture—or becoming slaked, as it is technically called. This it does more or less slowly by absorbing moisture from the air. As, however, the process would take too long, and as, moreover, the absorption of carbonic acid gas would also take place at the same time, lime is generally slaked in another way. This can be done by simply adding water. An objection to this method is, that the lime is not so uniformly slaked as is desirable. It becomes gritty. The usual method is to cover it up with damp earth in heaps, and allow the moisture of the earth to effect the slaking. When lime absorbs water a new chemical compound is formed, known as lime hydrate; and so rapidly does the lime unite with water, that a great deal of heat is evolved in the operation, the temperature produced being considerably above that of boiling-water. The conversion of slaked lime into carbonate of lime or mild lime is a slower process. Sooner or later, however, it takes place, whether the lime is left on the surface of the soil or buried in it.

A knowledge of these elementary chemical facts is necessary in order clearly to understand the nature of the action of lime in agriculture.

The respective action of quicklime and mild lime is, on the whole, similar, although the former is in every

case very much more powerful in its effects than the latter.

Lime acts both mechanically and chemically.

Lime may be said to act on the soil both mechanically and chemically. It alters the texture of the soil, and affects its mechanical properties, such as its absorptive, retentive, and capillary powers with regard to water. It acts upon its dormant fertility, and decomposes its mineral substances as well as its organic matter. Lastly, its influence on the micro-organic life of the soil, which plays such an important part in the preparation and elaboration of plant-food, is of the highest importance. We cannot do better, therefore, than discuss its properties under the headings *mechanical*, *chemical*, and *biological*.

I. MECHANICAL FUNCTIONS OF LIME.

Action on Soil's Texture.

The effect of lime upon the texture of a soil is among its most striking properties. Every farmer knows well what a transformation is effected in the texture of a stiff clay soil by the application of a dressing of lime. The adhesive property of the soil—its objectionable tendency to puddle when mixed with water—is greatly lessened, and the soil is rendered very much more friable when it becomes dry. Several reasons exist for this change. In the

first place, the tendency to puddle in a clayey soil is due to the fine state of division of the soil-particles. The way in which lime counteracts this adhesive property is by causing a coagulation of the fine soil-particles. This flocculation or aggregation of the fine clay-particles, when mixed with water by lime, is strikingly demonstrated by adding to some muddy water a little lime-water. The result will be that the water will speedily be rendered clear, the fine clay-particles coming together and sinking to the bottom of the vessel. Even a very small quantity of lime will effect this change. This property possessed by lime, we may mention, is utilised in the treatment of sewage. As it is the fine clay-particles that are the chief cause of the puddling of clay soils, their flocculation does much to destroy this objectionable property. Another reason why lime renders a clay soil more friable when dry is, that lime does not undergo any shrinkage in dry weather. As clay soils shrink very much in drying, the mixture with such a substance as lime tends to minimise this tendency to cake in hard lumps. The effect of even a very small addition of lime to a clay soil, in the way of increasing its friable nature, is very striking, and can be easily illustrated by taking two portions of clay, into one of which a small percentage of lime is introduced, and working both into a plastic mass with water, and then allowing them to dry. It will be found that while the one is hard and resists dis-

integration, that portion to which the lime has been added crumbles away easily to a powder. This effect which lime has in "lightening" heavy soils has been known to last for years. The disintegrating effect of quicklime when applied to heavy soils is also due, it may be added, to the change undergone by the lime itself from the caustic state to the mild state.

Lime renders light Soils more cohesive.

Although it may seem somewhat paradoxical, lime, it would appear, in some cases exercises an effect upon the soil exactly the reverse of what has just been stated. That lime should act as a binding agent is only natural when we reflect on the way in which it acts when used as mortar. It is quite to be understood, therefore, that its action on light friable soils should be to increase their cohesive powers, and at the same time to increase the capillary power of the soil to absorb water from the lower layers. The extent of this action, of course, would depend on the form in which the lime is applied, and the amount. A striking example of the binding power of lime is to be found in certain soils extremely rich in lime, in which what is known as a lime-pan has been formed at some distance from the surface.

II. CHEMICAL ACTION OF LIME.

But more important probably than even its mechanical action is the chemical action of lime. It is a most

important agent in unlocking the inert fertility of the soil. This it does by decomposing different minerals and setting free the potash they contain. The disintegrating power of lime in this respect depends, of course, on its chemical condition, the caustic form being much more potent than the other forms. Its action in decomposing vegetable matter and rendering the inert nitrogen it contains available for the plant's use, is also one of its most important properties, and accounts for its beneficial action when applied to soils, such as peaty soils, rich in organic matter. Again, its use as a corrective for sour lands has long been practically recognised. The presence of acidity in a soil is hurtful to vegetable life. Lime, by neutralising this acidity, removes the sourness of the land, and does much to restore it to a condition suitable for the growth of cultivated crops. The generation of sourness in a soil is almost sure to give rise to certain poisonous compounds. Lime, therefore, in sweetening a soil, prevents the formation of these poisonous compounds. Badly drained and sour meadow-lands, as every farmer knows, are immensely benefited by the application of this useful manure ; for not merely is their sourness removed and their general condition ameliorated, but many of the coarser and lower forms of plant-life, which alone flourish on such soils, are killed out, and the more nutritive grasses are allowed to flourish instead. The action of lime in promoting the formation of a class of compounds of great im-

portance in the soil—viz., hydrated silicates—is worthy of notice. According to the commonly accepted theory, much of the available mineral fertilising matter of the soil is retained in the form of these hydrated silicates. Hence lime, by increasing these compounds, not merely adds to the amount of the available fertility in the soil, but also increases its absorptive power for food-constituents.

III. BIOLOGICAL ACTION OF LIME.

The last way in which lime acts is what we have termed biological. By this we mean the important *rôle* lime plays in promoting or retarding, as the case may be, the various kinds of fermentative action which go on so abundantly in all soils. The presence of carbonate of lime in the soil is a necessary condition for the process of nitrification. Lime is the base with which the nitric acid, when it is formed, combines; and as we have seen, when discussing nitrification, soils of a chalky nature are among those best suited to promote the natural formation of nitrates. This is one of the reasons for the beneficial effects produced by lime when applied to peaty soils. Not merely does it help to decompose the organic matter so abundant in such soils, but it also furnishes the base with which the nitric acid may combine when it is formed. But while the action of lime is to promote fermentation, it must not be forgotten that there may be cases

in which its action is rather the reverse of this. Fermentation of organic matter goes on when there is a certain amount of alkalinity present; while, on the other hand, the presence of acidity seems to retard and check it. Too great an amount of alkalinity, however, would, in the first instance, retard fermentation as much as too great acidity. It has been claimed that the addition of caustic lime to fresh urine may act in this way; and if this were so, the addition of lime to farmyard manure might, to a certain extent, be defended. The experiment, however, would be a hazardous one and not to be recommended, as loss of ammonia would most likely ensue.

Action of Lime on Nitrogenous Organic Matter.

The action of lime on nitrogenous organic matter is of a very striking kind, and is by no means very clearly understood. As we have pointed out, it sometimes acts as an antiseptic or preservative; and this antiseptic or preservative action has been explained on the assumption that insoluble albuminates of lime are formed. Its action in such industries as calico-printing, where it has been used along with casein for fixing colouring matter; or in sugar-refining, where it is used for clarifying the sugar by precipitating the albuminous matter in solution in the saccharine liquor; or lastly, in purifying sewage,—has been cited in support of this theory. While, however, there may be circumstances in which lime, especially in its caustic form, acts as

an antiseptic, its general tendency is to promote these fermentative changes, such as nitrification, so important to plant-life.

An important use of lime in agriculture is in preventing the action of certain fungoid diseases, such as "rust," "smut," "finger-and-toe," &c., as well as in killing, as every horticulturist and farmer knows, slugs, &c.

Recapitulation. .

We may, in conclusion, sum up in a single paragraph the different ways in which lime acts. Its action is mechanical, chemical, and biological. It acts on the texture of the soil, rendering clay soils more friable, and exerting a certain binding effect on loose soils. It decomposes the minerals containing potash and other food-constituents, and renders them available for the plant's needs. It further decomposes organic matter, and promotes the important process of nitrification. It increases the power of a soil to fix such valuable food-constituents as ammonia and potash. It neutralises sourness, and prevents the formation of poisonous compounds in the soil. It increases the capillary condition of the soil, prevents fungoid diseases, and promotes the growth of the more nutritive herbage in pasture-land.

CHAPTER XXI.

INDIRECT MANURES—GYPSUM, SALT, ETC.

GYPSUM.

IN the previous chapter mention was made of gypsum as a compound of lime, but no reference to its action as a manure was made. In the past, gypsum was used extensively and highly valued. It was found to be of especial value for clover; and there is a story told of Benjamin Franklin which illustrates the very striking nature of its action on this crop. It is related that he once printed with gypsum the words "This has been plastered" on a field of clover, and that for a long time afterwards the legend was plainly discernible on account of the luxuriance of the clover on the parts of the field which had been thus treated.

Mode in which Gypsum acts.

Despite the fact that gypsum is a most ancient manure, it is only of late years that we have come to understand the true nature of its action. For long it

was believed that the reason of its striking effect in promoting clover was due to the fact that, as clover was a lime-loving plant, the action of gypsum was owing to the lime it contained. That, however, the action of gypsum is not due to the fact that it supplies lime to the plant, seems evident when it is stated that were this so, any other form of lime would have the same beneficial effect. It is well known, however, that this is not so. Besides, as we have already pointed out, lime is not a constituent which most soils lack, so far as the needs of the crop are concerned. There is a certain amount of truth in the old belief that gypsum enriches the soil in ammonia by fixing it from the air. The power that gypsum has as a fixer of ammonia has already been referred to in the chapter on Farmyard Manure; but in this case the gypsum is brought in contact with the ammonia. The origin of this old belief was due to a misconception as to the amount of ammonia in the atmosphere. No doubt gypsum greatly increases the power of a soil to absorb ammonia from the air; but the quantity of ammonia in the air is so very trifling, that its action in this respect is hardly worth considering. The true explanation of the action of gypsum is to be found in its effect on the double silicates, which it decomposes, the potash being set free. Its action is similar to that of other lime compounds, only more characteristic. As a manure, therefore, its action is indirect, and its true function

is to oust the potash from its compounds. Its peculiarly favourable action on clover is due to the fact that clover specially benefits by potash, and that adding gypsum practically amounts to adding potash. Of course it should be borne in mind that the soil must contain potash compounds if gypsum is to have its full effect. Now, however, that potash salts suitable for manuring purposes are abundant, it may well be doubted whether it is not better to apply potash directly. Further, it must be borne in mind that gypsum is applied to the soil whenever it receives a dressing of superphosphate of lime, as gypsum is one of the products formed by treating insoluble phosphate of lime with sulphuric acid.

It is possible that gypsum may act as an oxidising agent in the soil, just as iron in the ferric condition does. It has a large quantity of oxygen in its composition, and under certain conditions may act as a carrier of oxygen to the lower layers of the soil. When it is used, it should be applied some months before the crop is sown.

Gypsum, therefore, although it contains two necessary plant-constituents, lime and sulphuric acid, cannot be regarded as a direct manure; and as its action comes to be more fully understood, its use, which was never very abundant in this country, will probably decrease. We have already, in the chapter on Nitrification, referred to the action of gypsum in promoting nitrification.

SALT.

The action of salt as a manure presents a problem which is at once of the highest interest and surrounded with the greatest difficulties. In view of the large quantities now used for agricultural purposes, a somewhat detailed examination of the nature of its action is not out of place in a work such as the present.

Antiquity of the Use of Salt.

The recognition of the manurial functions of salt dates back to the very earliest times. Its use among the ancients is testified by numerous allusions in the Old Testament; while, according to Pliny, it was a well-known manure in Italy. The Persians and the Chinese seem also to have used it from time immemorial, the former more especially for date-trees.

Nature of its Action.

Despite, however, the great antiquity of its use, much difference of opinion seems always to have existed as to the exact method of its action, and as to its merits as a manure in promoting vegetable growth. It furnishes, in fact, a good example of the difficulty which exists in the case of many manures, whose action is chiefly indirect, of fully understanding their influence on the soil and on the crop. In fact, the action of salt is probably more complicated than that of any other manurial substance.

Salt not a necessary Plant-food.

We have already seen that neither sodium nor chlorine—the two constituent elements of salt—are in all probability absolutely necessary plant-foods. If they are necessary, the plant only requires them in minute quantities. Despite this fact, soda is an ash-constituent of nearly every plant, and in many cases one of the most abundant. In amount it is one of the most variable of all the ash-constituents, being present in some plants only in minute quantities, while in others it occurs in large quantities. Mangel and plants of the cabbage tribe may be cited as examples of plants containing large amounts of soda in their composition. But the plants which contain it in largest quantity are those which thrive on the sea-coast, and it has been thought that for them at least salt is a necessary manure. This, however, does not seem to be the case. In fact, the amount of soda in a plant seems to be largely a matter of accident. It may be added that the succulent portions of a plant are generally richest in soda.

Can Soda replace Potash?

Again, it has been believed that soda is capable of replacing potash in the plant; but this does not seem to be the case to any extent. The view that soda is able to replace potash, it has been thought, is supported by the variation which exists in the proportion of soda

and potash in different plants. It must be remembered, however, that it is highly probable that most plants contain a larger quantity of ash-constituents than is absolutely necessary for their healthy growth. Especially is this the case with such a necessary plant-food as potash, of which there is generally present, in all likelihood, an excess. The variation in the quantity of potash and soda present in many plants under different circumstances can scarcely, therefore, be regarded as furnishing a proof of the replacement of potash by soda. Incidentally we may mention, as a fact worthy of notice, that cultivated plants have more potash and less soda in their composition than wild plants. What has been said of soda may be held to apply equally to chlorine, as it seems to be chiefly in the form of common salt that soda enters the plant. The amount of salt, therefore, present in plants must be regarded as largely accidental and dependent on external circumstances, such as the nature of the soil, &c.

Salt of universal Occurrence.

But even were salt a necessary plant-food, its occurrence in the soil is already of sufficient abundance to obviate any necessity for its application. It may be said to be of almost universal occurrence. Even the air contains it in traces. That this is the case in the neighbourhood of the sea-coast is well known; but even in air far inland, accurate analysis of the air would probably demonstrate its presence in greater

quantity than is commonly believed. It is a wise provision that plants absorb salt, for it increases their efficiency as food,—the function of salt as a constituent of animal food being of the very highest importance. It is an indispensable food-ingredient for animal life. With regard to ordinary farm-stock, the amount of salt which naturally occurs in their food is quite sufficient. In the case, however, of pastures in countries far removed from the sea, the custom of specially supplying stock with salt is common. This is done by placing a piece of rock-salt in the fields.

Special Sources of Salt.

The salt of commerce is obtained from various sources. Besides the sea, we have ample sources of salt in the large saline deposits found in many parts of Europe, especially in Austria, and in England in Cheshire.

The Action of Salt indirect.

From what has been said above, it is clear that the action of salt as a manure is indirect and not direct. What the nature of that indirect action is we shall now proceed to discuss.

In considering the evidence of the manurial value of salt, we are at once brought face to face with the fact that the experience of its action in the past has as often been unfavourable as favourable. Salt, it is well known, is both an antiseptic and a germicide. It is, indeed, one of the most commonly used of preserva-

tives. When applied in large quantities to the soil, it has a most deleterious action on vegetation. This hurtful action of salt has long been known; and it is as often mentioned in the writings of antiquity on account of its unfavourable as on account of its favourable action. Thus, for example, among the ancient Jews it was customary, after the conquest of a hostile town, to strew salt on the enemy's fields, for the purpose of rendering them barren and unfertile. And again, among the Romans, for the same purpose, salt was often spread on a spot where some great crime had been committed.

While, therefore, its unfavourable action has long been known, the fact that there are circumstances under which its action is, on the contrary, favourable for promoting vegetable growth has also been long recognised. The difficulty for the agricultural student is to reconcile these two seemingly contradictory experiences. For the English agriculturist the subject possesses especial interest, since in England it has been in the past most generally used and its action most discussed since the time of Lord Bacon, who discusses in his writings the action of solutions of it on different plants.

The true explanation of salt being so different in its action is to be found in the quantity applied, the nature of the soil, the crop to which it is applied, and the conditions under which it is applied—*i.e.*, whether it is applied alone or along with other manures.

Mechanical Action on Soils.

In the first place, it must be noted that salt exerts a mechanical action on the soil of a very similar kind to that exercised by lime. When applied to clay soils it causes a flocculation or coagulation of the fine clay-particles, and thus prevents the soil from puddling to the same extent as would otherwise be the case. In fact, an example of this action of salt when in solution causing the precipitation of fine suspended clayey matter, is afforded by the formation of deltas at the mouths of rivers. The power of clarifying muddy water is common indeed to saline solutions. Schloesing attributes the clarifying power of a soil to the presence of the saline matters it contains; and from this point of view it would appear that manures containing any saline substance may exert an important mechanical influence on the soil.

Solvent Action.

But a much more important property of salt is its solvent action on the plant-food present in the soil. Its action in decomposing the minerals containing lime, magnesia, potash, &c., is similar to the action of gypsum. By acting upon the double silicates it liberates these necessary plant-foods. It is not only on the basic substances upon which it acts, but also on the phosphoric and silicic acids, which it sets free. Its power of dissolving ammonia from the soil is con-

siderable. Experiments with a weak solution of salt on a soil by Peters and Eichhorn to test its solvent power, showed that the salt solution dissolved more than twice as much potash and nearly thirty times as much ammonia as an equal quantity of pure water did. When applied to the soil, it seems chiefly to liberate lime and magnesia. The exact nature of the chemical action taking place is a point of some dubiety. According to some, it is changed into nitrate of soda; according to others, into carbonate of soda. The latter theory seems to be the more probable one. Its action on the lime and magnesia compounds is to convert them into chlorides; and this chemical reaction explains the action that salt has in increasing the water-retaining and water-absorbing power of the soil; for the chlorides of magnesia and lime are salts which have a great power of attracting water from the air.

Again, the very fact that salt acts as an antiseptic may serve to explain its beneficial action in certain cases where it prevents rankness of growth. No doubt this was its function when applied along with Peruvian guano. This it might do by preventing too rapid fermentation (nitrification) of the manure, or by actually weakening the plant. Its action when applied with farmyard manure may also be similar. But while its effect in many cases may be towards retarding fermentation, on the other hand its action, when applied along with lime to compost-heaps, is

towards promoting more rapid decomposition. Probably a reaction takes place between the lime and the salt, the result of which is the formation of caustic soda.

Such are some of the ways in which salt may act. It must at once be seen how its action in one case will be favourable and in another case unfavourable. There must be fertilising matter present in the soil if it is to act favourably. Again, it will only be under such circumstances, where rankness of growth is likely to ensue, that its antiseptic properties will act favourably and not unfavourably.

Best used in small Quantities along with Manures.

Probably it is for these reasons that its action has been found to be most favourable when applied along with other manures and not alone. Applied along with nitrate of soda, as is commonly done, it doubtless increases the efficiency of the nitrate. Some plants seem to be undoubtedly benefited by salt: of these flax may be mentioned. The application of salt to plants of the cabbage tribe seems also to be highly beneficial. On mangels, along with other manures, it has also been found to have a very favourable effect. But with many crops its action has been proved to be less favourable.

Affects Quality of Crop.

Although salt has often been found to increase the quantity of a crop, the quality of the crop has been

made to suffer. Its action on beetroot has been more especially studied. The effect of its application is to lessen the total quantity of dry matter and sugar in the plant. This has been found to be the case both when the salt was applied alone and along with nitrate of soda and other manures. On potatoes, again, its action has been found to be deleterious, lessening their percentage of starch. The deleterious action of chlorides on the quality of potatoes is also seen when potassium chloride is applied. It is for this reason that potash should never be applied to the potato crop in the form of chloride.

In the late Dr Voelcker's opinion, the conditions under which salt had the most favourable action on the mangel crop was in the case of a light sandy soil, and applied at the rate of 4 to 5 cwt. per acre. Its action when applied to clay soils was not so favourable.

Rate of Application.

Lastly, the rate at which it may be applied will naturally vary. From 1 cwt. and even less, up to 6 cwt. or even more, has been the rate at which it has been commonly applied in the past. From what has been said, it will be seen that it is more likely to exert a favourable influence when applied only in small quantities.

CHAPTER XXII.

THE APPLICATION OF MANURES.

THE conditions which regulate the application of manures are many and varied, and the subject, it must be admitted, despite the large amount of investigation already carried out, is most imperfectly understood. For these reasons it is impossible to do little more than lay down certain general principles which may be of service to the agriculturist in guiding him in carrying out the manuring of his crops.

Influence of Manures in increasing Soil-fertility.

In the first place it may be asked, How far can what we may call the permanent fertility of a field be influenced by the application of manures? And to this question the answer must be made, that the influence of manuring in increasing soil-fertility is very slight and only very gradually felt. This is illustrated by the difficulty experienced in attempting to restore to a fertile condition a soil which has long been treated by

an exhaustive system of cultivation. In such a case it will be found impossible to restore the fertility of the soil, except very gradually. Farmers who farm in new countries, and in rich virgin soils, little realise sometimes how quickly they may impoverish the fertility of their soils by exhaustive treatment, and how slow the process of restoration is. Nor is this strange when we reflect on the relatively small quantities of fertilising ingredients we are in the habit of adding to the soil by the application of manures, and the nature of their action. The small rate at which they are applied, and the impossibility of distributing them equally in the soil, explain how comparatively limited their action must necessarily be. Some manures, it is true—viz., those which are soluble—are more equally distributed; but then such manures, from their very nature, are little likely to affect the permanent fertility of the soil.

Influence of Farmyard Manure on the Soil.

Of manures which have the best effect in improving a soil's permanent fertility, farmyard manure is undoubtedly the most important. This is owing partly to the fact that it is applied in such large quantities, and partly on account of its composition. Liberal manuring with farmyard manure, systematically carried out, will in time do much to build up a soil's fertility. But liberal manuring with artificial manures will also effect the same end. This it does in an indirect manner

by means of the increased crop residues obtained under such treatment. Indeed one of the speediest methods of bringing a soil into good condition is by heavily manuring certain green crops, and then ploughing them in.

Farmyard Manure v. Artificial.

The question how far farmyard manure may be supplanted by artificials is one often discussed. We have already referred to this question in the chapter on Farmyard Manure. It is possible that, with our increasing knowledge of agricultural science, we may in the future be able to dispense with farmyard manure, and make shift to do with artificials alone. At present, however, all our experience points to the fact that the most satisfactory results are obtained from manures by using artificials in conjunction with farmyard manure. It is better both for farmyard manure and artificial manures to be applied together,¹ so that they may mutually act as supplementary the one to the other. While this is so, there may be circumstances in which it will be best to use artificials alone. Where, for example, fields, owing to their situation, are inaccessible, and where the expense of conveying the bulky farmyard manure would be very considerable, it may be found more economical to apply the more concentrated artificial manures. With

¹ Though not necessarily at the same time or to each succeeding crop. There may be comparatively long intervals between the applications of farmyard manure in many cases.

few exceptions, however, it will be found most desirable to use artificial manures as supplementary to farmyard manure, and not as substitutes for it.

Farmyard Manure not favourable to certain Crops.

While the above is true, it may be well to point out one or two facts regarding the nature of the influence of farmyard manure on certain crops. For instance, it has long been recognised as inadvisable in strong rich soils to apply it directly to certain grain crops, such as barley and wheat, since such a practice is apt to encourage rankness of growth—an undue development of straw at the expense of the grain. It is consequently customary to apply farmyard manure to the preceding crop. The direct application of farmyard manure to wheat, however, according to Sir J. B. Lawes, is not fraught with unfavourable results where the soil is a light one; it is only when the soil is of a heavy nature that it is best to apply it to the preceding crop. Potatoes are another crop to which it is best not to apply it directly. On the other hand, many are of the opinion that mangels seem to be able to benefit from large applications of farmyard manure.

Conditions determining the Application of Artificial Manures.

In the application of artificial manures a large number of considerations have to be taken into account.

Among these may be mentioned the nature of the manure itself, and its mechanical and chemical condition ; the nature of the soil and its previous treatment with manures, as well as the nature of the climate, the nature of the crop, and the previous cropping. It may be well, therefore, to examine somewhat in detail some of these considerations.

Nature of the Manure.

Nitrogen, phosphoric acid, and potash exist in the common manures, as has already been pointed out, in different states of availability. Nitrogen, for example, may exist in a soluble or insoluble condition, as nitrates, as ammonia, or in various organic forms. Phosphoric acid, similarly, may exist in a soluble form, as it does in superphosphate of lime, or in an insoluble form, as it does in bones or basic slag. Potash, on the other hand, exists—or should exist—in artificial manures only in a soluble form. Now a correct knowledge of the behaviour of these different forms of the common manurial ingredients when applied to the soil is, in the first place, necessary for their successful and economical use.

Nitrogenous Manures.

Thus our knowledge of the inability of the soil-particles to retain nitrogen in the form of nitric acid, as well as our knowledge of the fact that nitrogen is in this form immediately available for

the plant's needs, teaches us that nitrate of soda should never be applied before the plant is ready to utilise it—in short, that it should only be applied as a top-dressing; and further, that the use of such a fertiliser in a damp season is less likely to be economical than in a dry one. Again, with regard to nitrogen in the form of ammonia salts, our knowledge of the fact that ammonia is retained by the soil-particles, and that before it becomes available for the plant's needs it has to undergo the process of nitrification, teaches us the desirability of applying it a short time before it is likely to be used. While, lastly, with regard to the nitrogen in the various organic forms in which it occurs, our knowledge of the rate at which these are converted into an available form in the soil will determine when they are best applied. Some forms of organic nitrogen are in a soluble condition, and are quite as speedy in their action as sulphate of ammonia. This is the case with a considerable proportion of the different organic forms of nitrogen present in guano. Other forms of organic nitrogen are only slightly less so—as, for example, dried blood, which ferments very speedily. With regard, therefore, to nitrates and ammonia salts, as well as the more quickly available organic forms of nitrogen, they should either be applied as a top-dressing after the plant has started growth, or only shortly before seed-time. Bones, shoddy, and the various so-called native guanos, should

be applied a considerable period before they are likely to be required—not later than the previous autumn.

Phosphatic Manures.

With regard to phosphatic manures the same considerations hold good. Inasmuch as phosphoric acid, whether applied in the soluble condition, as in superphosphate, or the insoluble form, as in bones, basic slag, &c., is not liable to be washed out of the soil, the risk of loss is very slight, and need not be taken into account. As we have pointed out in considering the action of superphosphate, phosphoric acid in this latter form is more speedily available to the crop, and the necessity of applying it much before it is likely to be used does not exist. Hence superphosphate and manures which contain any appreciable amount of soluble phosphoric acid, such as guano, should only be applied shortly before seed-time. Bones, basic slag, or mineral phosphate ought to be applied, on the other hand, a long time before they are likely to be used. Hence an autumn application is to be recommended in the case of such manures.

Potash Manures.

Lastly, with regard to potash manures, as these are soluble, there is no necessity for applying them much before they are likely to be absorbed by the plant. Some are of the opinion that potash is, except in the case of sandy soils, best applied some

little time before it is likely to be used, so as to permit of its being washed down into the soil—a process which takes place only comparatively slowly. As potash manures have often been found to give a better result on pastures during the second year than during the first, they are best applied in the autumn.

The above statement as to the behaviour of the different fertilisers when applied to the soil, has a not unimportant bearing on the quantities in which they may safely be respectively applied. The rate at which manures may be applied depends, as we shall immediately see, on other conditions; but what it is here desirable to point out is, that it is not safe to apply such manures as nitrate of soda, or, for that matter, sulphate of ammonia, in large quantities at a time. In fact these manures, especially the former, will best be applied in very small quantities, and rather in several doses. With regard to other manures, more especially phosphatic manures, the same reasons for small application do not exist.

The truth of the above statements is so obvious that it may be regarded as superfluous to make them. As, however, their clear apprehension is essential to understanding the conditions of successful manuring, no apology need be made for making them.

Nature of Soil.

Another condition which has to be taken into account in considering the application of manures is

the nature of the soil, as well as its previous treatment. Soils poor in organic matter are those which are most likely to be benefited by the application of nitrogenous manures. Soils of a dry light character require less phosphoric acid than they do of nitrogen and potash; while on a damp and heavy soil phosphatic manures are more likely to be beneficial than nitrogenous or potassic manures. Lastly, a soil rich in organic matter generally requires phosphates, and possibly potash. A point of considerable importance to notice is, that a soil rich in lime can stand a larger application of phosphoric acid than one poor in lime. As a rule, it will be found that the best results with potash will be obtained when applied to a sandy soil. The nature of the soil is an important consideration in determining how far it is advisable to apply readily soluble manures. To a very light and non-retentive soil the risk of loss in applying an easily soluble manure is considerably increased. The nature of the climate is also of importance. Thus, in a dry climate, manures of a soluble nature will have a better effect than in a wet climate, while the opposite will be the case with the more slowly acting manures.

Nature of previous Manuring.

A consideration of equal importance is the previous treatment of the soil with manure. For example, where a soil has been liberally treated with farmyard manure, it has been found that mineral manures have

a very inferior effect to that obtained by nitrogenous manure. Lawes and Gilbert have found this to be strikingly the case in their experiments on the growth of wheat. In these experiments it was found that the application of mineral manures was accompanied with little or no benefit to the crop, whereas very striking results followed the application of nitrogen. This they attributed to the fact that the supply of mineral fertilisers in the straw of the farmyard manure is largely in excess of the supply of nitrogen. The nature of the action of the manure previously applied is also to be taken into account in determining how long its influence may probably last. Where, for example, the manure has been nitrate of soda or sulphate of ammonia, it may be safely concluded that its direct influence is no longer felt a year after application. The influence of superphosphate of lime, while scarcely so temporary, may be said to last only for a comparatively short time.¹ On the other hand, when the manure applied is of a slow-acting nature, such as bones or basic slag, its influence will probably be felt for a number of years.

Nature of the Crop.

But more important than any of the above-mentioned conditions is the nature of the crop itself.

¹ Of course what is meant here is the direct influence of such manures. Their indirect value may be shown in the soil by the increased crop residues they give rise to.

Our knowledge of the requirements of the different farm crops is still very imperfect. A very wide experience, however, of the effect of different manures on different crops, has conclusively proved that their manurial requirements differ very considerably. The subject is complicated by other considerations, such as the nature of the soil, &c.; but notwithstanding this fact, certain points seem to be pretty well established.

In seeking to understand the respective requirements of the different crops for different fertilisers, two important considerations must be borne in mind. These are—(1) *the quantities of the three fertilising ingredients—nitrogen, phosphoric acid, and potash—which different crops remove from the soil*; and (2) *the different power crops possess of assimilating these ingredients*.

*Amounts of Fertilising Ingredients removed from
the Soil by different Crops.*

The most convenient way of instituting a comparison between the requirements of the different crops in this respect is by calculating the amount, in pounds, of nitrogen, phosphoric acid, and potash, which average amounts of the different crops remove per acre. The following table shows this for the common crops:—

		Nitrogen.	Phosphoric Acid.	Potash.
Mangels	{ Root, 22 tons . . .	87	36.4	222.8
	{ Leaf	51	16.5	77.9
	Total crop . . .	138	52.9	300.7
Turnips	{ Root, 17 tons . . .	63	22.4	108.6
	{ Leaf	49	10.7	40.2
	Total crop . . .	112	33.1	148.8
Beans	{ Grain, 30 bushels . .	77	22.8	24.3
	{ Straw	29	6.3	42.8
	Total crop . . .	106	29.1	67.1
Red clover hay, 2 tons . . .		102	24.9	83.4
Swedes	{ Root, 14 tons . . .	70	16.9	63.3
	{ Leaf	28	4.8	16.4
	Total crop . . .	98	21.7	79.7
Oats	{ Grain, 45 bushels . .	38	13.0	9.1
	{ Straw	17	6.4	37.0
	Total crop . . .	55	19.4	46.1
Meadow hay, 1½ ton, . . .		49	12.3	50.9
Wheat	{ Grain, 30 bushels . .	33	16.0	9.8
	{ Straw	15	4.7	25.9
	Total crop . . .	48	20.7	35.7
Barley	{ Grain, 30 bushels . .	35	16.0	9.8
	{ Straw	13	4.7	25.9
	Total crop . . .	48	20.7	35.7
Potatoes, 6 tons		47	21.5	76.5
Maize	{ Grain, 30 bushels . .	28	10.0	6.5
	{ Stalks, &c.	15	8.0	29.8
	Total crop . . .	43	18.0	36.3

From the table it will be seen that the crops which remove the largest quantities of all three fertilising ingredients are the root crops—mangels and turnips; that beans remove twice as much nitrogen as the cereals—oats, barley, and wheat—which, in this respect, practically differ very little from one another; while potatoes remove about the same quantity of nitrogen as the cereals. It will further be noticed that the amounts of phosphoric acid removed by the different crops differ very much less than those of nitrogen and potash. Mangels remove slightly more, and turnips slightly less, than double the amount removed by cereals. Meadow-hay, it will be seen, of all crops removes the least phosphoric acid.

In looking at the amounts of potash, we are at once struck by their great discrepancy. Such a crop as mangels removes more than six times as much potash from the soil as the cereals. Turnips also make large demands on this ingredient, removing over four times as much as the cereals. Leguminous crops, such as red clover and beans, remove about twice as much.

Capacity of Crops for assimilating Manures.

Instructive though these figures undoubtedly are, *they must not be regarded, as often erroneously they are, as furnishing by themselves sufficient data upon which to base the practice of manuring.* A consideration which is of much greater importance is the capacity that different crops possess for assimilating the

various manurial ingredients from the soil. Considered from the point of view of absolute amount, there is in most soils an abundant supply of plant-food; but of this amount only a small proportion is available. Further, the amount of this available plant-food will vary with different crops—one crop being able to grow where another crop would starve. As illustrative of this, in the Norfolk experiments it was found that the turnip was able to assimilate potash from a soil on which the swede was practically starved. It is on this fact more than any other that the principles of manuring are based. Several explanations of the different capacities crops possess of assimilating their food may be put forward. And we may here point out that crops belonging to the same class exhibit, on the whole, a certain amount of similarity in their manurial requirements. Thus, for example, we may say that *gramineous crops* so far resemble one another in possessing *small capacity for assimilating nitrogen*, *root crops* for *assimilating phosphoric acid*, and *leguminous crops* for *assimilating potash*, and that, consequently, these crops are generally most benefited by the application, respectively, of nitrogen, phosphoric acid, and potash. But while a certain general resemblance exists, crops belonging to the same class differ in many cases very considerably, as we shall immediately see.

Difference in Root Systems of different Crops.

One explanation of the different capacity possessed by different crops for absorbing plant-food from the soil is to be found in the difference of their root systems. Every agriculturist knows that crops in this respect differ very widely. Crops having deep roots will naturally have a larger surface of soil from which to draw their food-supplies than crops having shallower roots. Such crops as red clover, wheat, and mangels are able to draw their food-supplies from the subsoil to an extent not possessed by shallower-rooted crops, such as barley, turnips, and grass. Crops having surface-roots, on the other hand, have often greater capacity for assimilating nitrogen,—this ingredient, as has already been pointed out, being chiefly located in the surface-soil. The tendency of growing shallow-rooted crops will therefore be towards impoverishing the surface-soil; whereas the occasional growth of a deep-rooted crop brings the plant-food in the subsoil into requisition. In this connection it may be well to draw attention to the singular capacity possessed by certain crops for absorbing nitrogen. Of these the case of clover is the most striking, and has long puzzled agriculturists. The discovery, which has been repeatedly referred to in these pages, that the leguminous order of crops, to which clover belongs, have the power of absorbing the free nitrogen of the air through the agency of micro-organic life in the plant and in

the soil, has furnished an explanation of this long-debated problem.

Period of Growth.

A further reason is the difference in the period of a crop's growth. A crop which grows quickly, and consequently occupies the ground during a comparatively short period, will naturally require a richer soil, and therefore a more liberal treatment with manure, than one whose growth is more gradual.

Another consideration is the season of the year during which active growth of the crops takes place. For example, in the case of the wheat crop, active growth takes place in spring and ceases early in the summer. Since, however, nitrification goes on right through the summer, and nitrates are most abundant in the soil in late summer and autumn, such a crop as wheat is ill suited to obtain any benefit from this bountiful provision of nature, and is consequently particularly benefited by the application of nitrogenous manures. Root crops, on the other hand, sown in summer, continue their active growth into autumn, and are thus enabled to utilise the nitrates formed in the process of nitrification. The custom of sowing a quickly growing green crop, such as rye, mustard, rape, &c., after a wheat crop, is a practice which aims at conserving the nitrates and preventing their loss by autumn and winter rains. The name "catch crop" has been applied to such a crop. By plough-

ing under the green crop, the nitrogen removed from the soil in the form of easily soluble nitrates is restored in an insoluble organic form, and the soil is at the same time enriched by the addition of much valuable organic matter.¹

It is chiefly the above facts that form the scientific basis of the long-pursued practice of the rotation of crops.

Variation in Composition of Crops.

A point of considerable interest is the influence exerted by manures on the composition of crops. It has been assumed in the preceding pages that the composition of crops of the same plant is uniform; but this is not strictly the case, as it has been proved that not merely the manure and soil have an appreciable influence on the crop's composition, but so also has the climate.

Absorption of Plant-food.

The laws regulating the absorption of plant-food are most interesting, although, unfortunately, very imperfectly understood as yet. The fertilising ingredients are capable of considerable movement in the plant, and are only absorbed up to a certain period of growth. This in many plants is reached when they flower. After this period they are no

¹ This is very concisely and clearly put in Mr Warington's admirable 'Chemistry of the Farm.'

longer capable of absorbing any more food. The popular belief that plants in ripening exhaust the soil of its fertilising matters is consequently a fallacy.

Fertilising Ingredients lodge in the Seed.

The tendency of fertilising matters is to move upward in the plant as it matures, and finally to become lodged in the seed. It is for this reason that the cereals prove such an exhaustive crop. That nature, however, can in certain cases be very economical of her food-supplies, is strikingly illustrated by the fact that much of the fertilising matter contained in the mature leaves in autumn passes back into the tree before the leaves fall from it.

Forms in which Nitrogen exists in Plants.

The form in which nitrogen is present in the plant is chiefly as albuminoids. As, however, albuminoids belong to that class of bodies known as colloids, which cannot easily pass through porous membranes like those forming the walls of plant-cells, they are changed during certain periods of the plant's growth into amides, which are crystalloids, and consequently able to move freely about in the plant. Amides are most abundant in young plants during the period of their most active growth, and as the plant ripens the amides seem to be largely converted into albuminoids.

While the subject is not very clearly understood, it would seem to be pretty conclusively proved that

there is a direct relation between the amount of the phosphoric acid and of the nitrogen absorbed.

Bearing of above Facts on Agricultural Practice.

The bearing of these facts upon practice is obvious. In the first place, they show how important it is that plants should be well fed when they are young, and that in the practice of green manuring it is best to plough in the crop when it is in flower, as no additional benefit is gained by allowing it to ripen, seeing that no further absorption of fertilising ingredients takes place after the period of flowering.

Influence of excessive Manuring of Crops.

The influence of large quantities of manures is seen in the case of certain root crops. It is found, in such a case, that while the roots are larger, they are more watery in composition and of less nutritive value. Again, it seems to be a fact pretty generally known to practical men, that nitrate of soda seems to have a bad effect on the quality of hay. It would seem, further, that the influence of nitrogenous fertilisers on cereals is to increase the percentage of nitrogen in the grain, but that they have no such influence in the case of leguminous crops. Phosphatic manures, on the other hand, in the case of leguminous crops, seem to have the effect of diminishing the amount of nitrogen in the seed.

CHAPTER XXIII.

MANURING OF THE COMMON FARM CROPS.

IN this chapter we shall attempt to summarise briefly the results of experiments on the manuring of some of the commoner crops, and we shall start with the manuring of cereals.

CEREALS.

As we have already pointed out, a certain similarity in the manurial requirements of the different members of this class exists. They are characterised, for one thing, by the comparatively small quantity of nitrogen they remove from the soil—less than either leguminous or root crops. Of this nitrogen the larger proportion—amounting to two-thirds—is contained in the grain, the straw only containing about a quarter of the total amount of nitrogen in the plant. The amount of phosphoric acid they remove from the soil is not much

less than that removed by the other two classes of crops; but this, again, is also chiefly in the grain. It is on this account that the cereals may be regarded, in a sense, as exhaustive crops, seeing that the grain is almost invariably sold off the farm. But, on the other hand, owing to the comparatively small demands they make on fertilising ingredients, cereals will continue to grow on poor land for a longer period than most crops,—a fact of very great importance for mankind.

Epecially benefited by Nitrogenous Manures.

Despite the fact that cereals remove comparatively little nitrogen from the soil, it is somewhat striking to find that they are chiefly benefited by the application of nitrogenous manures. This fact may be explained by the shortness of the period of their growth, and the fact that they assimilate their nitrogen in spring and early summer, and are thus unable to utilise to the full the nitrates which accumulate in the soil during later summer and autumn. As they seem to absorb their nitrogen almost exclusively in the form of nitrates, they are especially benefited by the application of nitrate of soda.

Power of absorbing Silicates.

A characteristic feature in the composition of cereals is the large amount of silica they contain. In common with the grasses, they seem to possess a

power, not possessed by other crops, of feeding upon silicates.

The special manure, therefore, required for cereals is a nitrogenous manure, and that, as a rule, of a speedily available character, such as nitrate of soda or sulphate of ammonia. Furthermore, certain members of the group are also specially benefited by phosphatic manures.

We shall now consider individually a few of the more important cereal crops.

BARLEY.

Of cereal crops barley deserves to be considered first, owing to the fact that it is, of all grain crops, the most widely distributed. In England, in amount, it comes next to wheat among cereals. Its habits have also been studied in a very elaborate and careful manner, and have been made the subject of many experiments, both in this country and abroad.

Period of Growth.

The first point to notice about barley is the fact that its period of growth is a short one. This has a most important bearing on its treatment with manure. It may be said to ripen, on an average, in thirteen or fourteen weeks in this country; although in Norway and Sweden its period of growth is much less—viz., from six to seven weeks. Indeed no fewer than three

crops have been obtained in one year in certain districts in these countries, and two crops are common. With regard to the period of its growth, it differs from wheat, which in its general manurial requirements it resembles. Wheat, which is largely sown in autumn, has four or five months' start of barley. From the fact that it is a short-lived crop, and that its roots are shallower than wheat, and draw their nourishment chiefly from the surface-soil, it benefits to a greater extent from liberal manuring than wheat, which is more independent of artificial supplies of fertilisers.

Most suitable Soil.

Again, while wheat does well on a heavy soil, and does not require a fine surface-tilth, barley does best on a light, rich, friable soil. It has, however, been very successfully grown on a heavy soil after wheat. Barley benefits more than wheat does from the application of superphosphate of lime, or some other readily available phosphatic manure. This may be accounted for by its shorter period of growth and shallower root system, which thus prevent it drawing much mineral sustenance from the subsoil. In fact, spring-sown crops, as a rule, benefit more from superphosphate than autumn-sown crops. The exhaustion of a soil under barley is essentially, as in the case of wheat, one of nitrogen, as Sir J. Henry Gilbert has pointed out.¹

¹ See his Lecture on the Growth of Barley.

Farmyard Manure not suitable.

It has been urged, with some show of reason, that farmyard manure is not suitable for barley, as its action is too slow to have much influence on so short-lived a plant, and that only quick-acting manures should be used. Where farmyard manure is applied, it should be to the preceding crop; and this is advisable for more reasons than one.

Importance of uniform Manuring of Barley.

The use to which barley is put—viz., for malting purposes—renders the uniformity of its composition a point of great importance. Since its quality is very largely influenced by its treatment with manures, special care has to be exercised in their application. Grown as it generally is after roots, fed off with sheep, its quality, it is alleged, is apt to suffer from the unequal distribution of the manure applied in this way. It has consequently been recommended, in order to avoid this inequality, rather to grow a wheat crop immediately preceding the barley.

Norfolk Experiments on Barley.

Mr Cooke, in summing up the results of the interesting Norfolk experiments on barley, points out that in these experiments barley always was benefited by nitrogenous manures, sometimes by superphosphate

of lime, and more rarely by potash; that of nitrogenous manures those of quickest action exerted the best influence. On an average it was found that 1 cwt. nitrate of soda per acre gave an increase of 8 bushels of barley, and 2 cwt. gave 14 bushels; while $\frac{3}{4}$ cwt. sulphate of ammonia (*i.e.*, the amount containing the same quantity of nitrogen as 1 cwt. nitrate of soda) gave only $5\frac{1}{2}$ bushels of an increase, and $1\frac{1}{2}$ cwt. (= 2 cwt. nitrate of soda) gave 10 bushels.

Mr Cooke recommends the following manures for the barley crop. From $\frac{1}{4}$ to 1 cwt. of nitrate of soda, according to previous treatment of soil; from 1 to 2 cwt. super; and where it is required, from $\frac{1}{2}$ to 1 cwt. muriate of potash.

Proportion of Grain to Straw.

Professor Hellriegel, the distinguished German investigator, has carried out most elaborate experiments on a small scale, with a view to investigating the habits of the barley plant. In the most perfectly developed of these plants, grown under the most favourable conditions, he found that the grain and straw were about equal in weight. Such a proportion of grain is, however, never realised in practice, the proportion of 2 of grain to 3 of straw being probably the common one.

WHEAT.

Wheat occupies the first position amongst cereals, in respect of extent of cultivation, in England. As a rule it is sown in autumn, although it is also sown in spring. It is generally taken after rotation grasses or a leguminous crop, such as peas or beans, or after potatoes or roots.

Unlike barley, it does best on a clay soil, or at any rate on a firm soil, and requires a moist seed-bed. From the fact that wheat is often sown after such a crop as potatoes or a root crop to which a liberal application of manure has been given, it is not so necessary to manure it except with a top-dressing of nitrate of soda. In short, it is usually considered highly desirable to get land into "good heart" before wheat, so that the wheat may obtain its nourishment from the residue of the previous crop and the farmyard manure previously applied.

Although, therefore, as a rule, the only manure it will be found necessary to add to wheat is a nitrogenous manure, such as nitrate of soda or sulphate of ammonia, still there are circumstances in which it will be well to supplement these by phosphatic or even potassic manures. On a light soil it may be advisable to add superphosphate of lime, guano, or bone-meal, in quantities of 2 to 3 cwt. per acre, in addition to a nitrogenous manure.

Rothamsted Experiments on Wheat.

Of experiments carried out on the growth of wheat, those which have now been in progress for over half a century at Rothamsted are the most valuable and famous. In these experiments the comparative value of nitrogen and mineral manures on this crop was strikingly exemplified. The former gave a most marked increase in the crop, while with the latter little or no increase was obtained. A combination of nitrogenous and mineral manures, on the other hand, gave the most striking results. An explanation of these results may be afforded by the fact that in ordinary farming an excess of mineral matter, as compared with nitrates, is returned to the soil in the crop residues and in the straw of the farmyard manure.

Of nitrogenous manures, nitrate of soda, on the whole, showed better results than sulphate of ammonia.

Continuous Growth of Wheat.

The possibility of growing fair crops of wheat year after year for fifty years on the same land, and that without any manure whatever, is among the most striking of the results of these famous Rothamsted wheat experiments.

Flitcham Experiments.

In conclusion, we may refer to Mr Cooke's Flitcham experiments. These were carried out for the purpose

of ascertaining the most suitable manure for the wheat crop under different conditions.

It will be sufficient here to give the recommendations made by Mr Cooke as the practical outcome of these experiments.

He recommends the application of 10 tons of farm-yard manure on light or mixed soils, after rotation seeds, ploughed in in the autumn, with from $\frac{1}{4}$ to 1 cwt. of nitrate of soda, sown in the spring. In certain cases farmyard manure will be sufficient without the nitrate of soda. When farmyard manure is not available, the most effective and economical substitute is 4 cwt. per acre of rape-cake, ploughed in in the autumn, or 1 cwt. of sulphate of ammonia, sown in the spring, with, in either case, 1 cwt. of nitrate of soda as a spring top-dressing. In addition to the above, on land in doubtful agricultural condition, or exceptionally deficient in one or other of these ingredients, Mr Cooke recommends the addition of 2 cwt. superphosphate, or 1 cwt. muriate of potash, or both of these manures, ploughed or harrowed in in autumn.

OATS.

Like barley, oats are generally sown in spring, and, like barley, may be described as a shallow-rooted crop. They require, therefore, manures which are readily available, and their demands on the different fertilising ingredients are very similar to

barley. The manures which will pay best, consequently, for oats, are nitrate of soda, used as a top-dressing, and superphosphate of lime, applied along with the seed. Probably upon no other crop is nitrate of soda so safe and so effective as upon oats. In some respects, however, oats differ strikingly from barley.

A very hardy Crop.

In the first place, oats are a much hardier crop than barley or wheat. They can grow on a wonderfully wide range of soil, and under comparatively adverse circumstances, both of climate and situation. They are better suited for a damp climate such as our own than a warm climate. They may be described as of all crops the least fastidious, and will flourish on sandy, peaty, or clayey soils. While this is so, they show a preference for soils rich in decayed vegetable matter. It is for this reason that they flourish so well on soils freshly broken up from pasture, and are often the first crop to be grown on such soils.

Require mixed Nitrogenous Manuring.

Stoeckhardt has found, in experiments on the manuring of the oat crop, that they greedily absorb nitrogen during nearly the whole period of their growth, and that, consequently, it is desirable to manure them with a mixed nitrogenous manure which shall contain nitrogen, both in a readily available form to supply the plant during the early stages of its growth, and in a

less available form for the later stages of growth. He was of the opinion that in this way a continuous and satisfactory growth of the crop would be promoted.

Arendt's Experiments.

The oat-plant has been made the subject of many elaborate investigations. Of these, those carried out by Arendt are the most elaborate and best known. In these experiments the composition of the oat-plant at different stages of growth was investigated. It was found that the oat-plant increased during the whole period of its life, and that two-thirds of the nitrogen absorbed was absorbed during the later period of growth. It has since been shown, however, that the absorption of nitrogen is very much influenced by circumstances. Indeed its composition is peculiarly susceptible to the influence of manures, and especially the influence of weather. Thus Arendt found that the assimilation of nitrogen is checked by cold wet weather; while, on the other hand, it is promoted by warm dry weather. The grain of oats grown in warm seasons is better developed, and in composition more nutritious (*i.e.*, contains more nitrogen), than that of oats grown in wet seasons, while the reverse is the case with the straw.

"Avenine."

A point of considerable interest in connection with the composition of oats is the fact that it contains a

body which exerts a strikingly stimulating effect on the nervous system of the animal, and to which the name "avenine" has been given.

Quantities of Manures.

The quantities of manures which may be applied to the oat crop are similar in amount to those which ought to be applied to barley—from $\frac{1}{2}$ to 1 cwt. of nitrate of soda, and from 2 to 3 cwt. superphosphate of lime. Very often, however, the oat crop receives directly little or no manure. In the Highland and Agricultural Society of Scotland's experiments, sulphate of ammonia was found to be of very much less value than nitrate of soda as a manure for oats. Potash manures, especially muriate of potash, had a very beneficial effect. The general conclusions drawn from these experiments were, that the treatment of the land should be such as to accumulate organic matter in it, to prevent too great a loss of moisture, and to provide the young plant with manures that come speedily into operation.

GRASS.

The manuring of grass is a question of very great interest and importance, but is, at the same time, beset with peculiar difficulties. Grass is grown under two conditions—first, that grown on soils exclusively

set apart for its continuous growth (permanent pasture); and secondly, that grown for the purpose of being converted into hay and of providing pasture in the ordinary rotation of crops (rotation seeds). The manuring of the former is somewhat different from the manuring of the latter.

Effect of Manure on Herbage of Pastures.

The nature of the herbage growing on pasture is very much influenced by the manure applied. This, indeed, is one of the most noteworthy features connected with the manuring of grass, and has been especially observed in the Rothamsted experiments, where the influence of the different manures on the various kinds of herbage has been investigated with great care. The herbage constituting pasture is, as every farmer knows, of a varied description. We have in pastures a mixture of plants belonging both to the gramineous and leguminous classes, as well as a variety of weeds. Now the result of the application of different manures tends respectively to foster the different kinds of grasses. Thus when one kind of manure is applied, grasses of one kind tend to predominate and crowd out grasses of another. It has been found that *the more highly pasture-land is manured the simpler is the nature of its herbage* (that is, the fewer are the different kinds of herbage growing on it). *Unmanured pasture, on the other hand, is more complex in its herbage.* The result is, that the

application of manure to pasture-land is attended with certain dangers. To maintain good pasture it is desirable to effect a proper balance between the different kinds of grasses. For this reason permanent pasture may be said to be, of all crops, the least commonly manured. As a rule it is only manured by the droppings of the cattle and sheep feeding upon it.

Influence of Farmyard Manure.

It is found that the influence of farmyard manure upon the composition of the pasture does not tend, to the same extent, to the undue development of one type of herbage over another; and in this respect it is probably to be preferred to artificial manures.

The same reasons, however, do not hold with regard to rotation seeds, where an abundant growth is desired, and complexity of herbage is not so important. A further reason which exists for the manuring of meadow-land is the greater impoverishment of the soil taking place under such conditions. As illustrating the influence of different manures on different kinds of herbage, it may be mentioned that in New England wood-ashes, a manure commonly used there, have been observed, when applied to pasture, to bring in white clover, and that the application of gypsum had the same effect. An explanation of this fact may be found in the influence of potash on leguminous crops. The chief value of wood-ashes as a manure is due to the large percentage of potash they

contain, while the value of gypsum is probably to be accounted for by the fact that it has an indirect action, and sets free potash from its inert compounds in the soil. In the Rothamsted experiments this point has been verified, and potash has been shown to increase the proportion of leguminous plants on a grass-field. Nitrogenous manures, on the other hand, more especially sulphate of ammonia, have been found to increase the proportion of grasses proper, and to diminish the proportion of leguminous plants. The effect of farmyard manure, while less marked in inducing simplicity of herbage, has a similar effect to sulphate of ammonia; while phosphates and other mineral manures exercise an influence similar to that of potash. Mixtures of mineral and nitrogenous manures gave the largest returns obtained, but their influence was to increase the proportion of grasses proper. Sewage irrigation also tends chiefly to develop grasses.

Influence of Soil and Season on Pastures.

Manures are not the only factors influencing the quality of pastures. The nature of the soil, as well as the age of the pasture and the character of the season, exert a very considerable influence. Grass growing on damp or badly drained soil is invariably of poor quality, the coarser grasses predominating. Old pastures, again, are generally of better quality than new ones.

MANURING OF MEADOW-LAND.

Nitrate of soda is a common manure for grass grown for hay. It is often applied at the rate of 2 or 3 cwt. per acre. It is best, however, to apply it in smaller doses. On soils where lime is abundant, superphosphate may be applied, if necessary, at the rate of 2 or 3 cwt. per acre, or bones at a similar rate. Basic slag has been found to meet with good results as a manure for grass-land, especially where the soil is rich in organic matter.

Bangor Experiments.

Mr Gilchrist of University College, Bangor, as a result of numerous experiments carried out in different parts of Wales, recommends for rye-grass and clover hay on land in good condition 1 cwt. of nitrate of soda or sulphate of ammonia per acre, the former being applied about the middle of April, the latter during March. For land in poor condition, the addition of 2 cwt. of superphosphate is recommended—this to be applied some time between December and March. Farmyard manure may be usefully applied to young grass and clover seeds in the autumn, more especially on light soils. For meadow-land which is growing hay every year, Mr Gilchrist further recommends the following 4-course rotation of manuring:—

First year, 15 tons farmyard manure, applied in the autumn.

Second year, 1 cwt. nitrate of soda.

Third year, 4 cwt. basic slag or 3 cwt. superphosphate and 1 cwt. nitrate of soda.

Fourth year, 1 cwt. nitrate of soda.

Norfolk Experiments.

Mr Cooke, from his Norfolk experiments, recommends the following manures for rotation seeds:—

One to $1\frac{1}{2}$ cwt. nitrate of soda as a top-dressing in early spring. Where the clover plant is a good one, and it is particularly desired to cultivate it, he recommends as a dressing 1 cwt. of muriate of potash per acre, to be applied immediately after the clover is sown. The practice of dressing growing seeds in their first winter has, so far as the experiments in Norfolk go, less to recommend it than the earlier dressing.

MANURING OF PERMANENT PASTURES.

In this case the manure should be applied so as not to impair the quality of the herbage. Slow-acting manures are consequently best, such as basic slag or bones, which have been found to be of special value. On wet or marshy land after draining, lime is perhaps one of the best manures to apply in the first instance. As we have already said, farmyard manure will do more to maintain the quality of pasture than any kind of artificial manure. Mr Cooke is of opinion that no system of manuring yet discovered will both

thicken and improve the herbage at all equally in success to the careful and regular feeding upon the grass of cattle or sheep, the animals having a good allowance of decorticated cotton-cake, or even of linseed-cake.

ROOTS.

Of all crops roots may be said to require the most liberal application of manure, and to respond most freely to it. They contain large quantities of the fertilising ingredients—nitrogen, phosphates, and potash—and may be regarded as exceedingly exhaustive crops. This is especially the case with regard to mangels, which make particularly large demands on a soil's fertilising ingredients.

Turnips are characterised by the large amount of sulphur they contain; and, according to some, this explains the beneficial effect which gypsum has when applied to them as a manure. This, however, is more probably to be explained by the indirect action of gypsum in setting free the potash of the soil. The fact that the successful cultivation of root crops depends on the application of large quantities of manure, is recognised in practice, as they receive the most manure of any crop of the rotation. Roots flourish best on a light soil which is neither too wet nor too dry; but with liberal manuring and careful tillage, they may be said to do well on any soil. Mangels

are generally more benefited by the application of nitrogenous manures than are turnips or swedes, which, it would seem, have a greater power of absorbing nitrogen from the soil than the first-named crop; but it is a mistake to suppose that any of the root crops are not dependent on a ready supply of nitrogen; and the fact that large crops of turnips can often be grown by the application of superphosphate alone, may be taken as a proof that the soil contains plenty of nitrogen. Mangels are, from their deeper roots, more capable of drawing their supply of phosphoric acid from the soil than turnips. They respond, therefore, as a rule, less freely than turnips or swedes to an application of superphosphate. Generally speaking, we may say that the characteristic manure for turnips is superphosphate, and that for mangels is a nitrogenous manure such as nitrate of soda or sulphate of ammonia.

A special reason for manuring root crops is the fact that they are more liable to disease than other crops; and this is especially the case in the early stages of their growth. One of the great benefits conferred on the turnip crop by an application of superphosphate, is the help it gives the crop to pass safely the critical period of its growth. The superphosphate is best drilled in with the seed, in quantities varying from 3 to 5 cwt. In Scotland, it may be well to point out, the manure applied to this crop is very much in excess of the amount customarily applied in England; for in the former country larger applications of manure

may be profitably employed. Roots generally receive a large dressing of farmyard manure. Salt has been found in some districts to have a very good effect on the mangel crop, and potash is often found to amply repay application.

Influence of Manure on Composition.

A most interesting point in connection with the manuring of roots is the effect of manure on their composition. This has been most elaborately investigated at Rothamsted and elsewhere. Thus it has been found that the effect of the application of excessive quantities of nitrogenous manures is to produce too great a development of leaves at the expense of the roots.

Nitrogenous Manures increase Sugar in Roots.

Nitrogenous manures also tend to increase the proportion of sugar and diminish the proportion of nitrogenous matter in roots. This has an important bearing on the treatment of roots which are cultivated for their sugar, such as beets, in the growth of which nitrate of soda is the chief artificial manure applied.¹

The leaf, it may be pointed out, contains a larger percentage of dry matter, both in swedes and in turnips, than the root.

¹ Small roots are found to contain a larger proportion of sugar than large roots.

Amount of Nitrogen recovered in Increase of Crop.

With regard to the amount of nitrogen recovered in the increased crop of mangel and roots when manured with different nitrogenous manures, it was found at Rothamsted, as an average of six years, that the following percentages of nitrogen were recovered: When nitrate of soda was applied, 60 per cent of the nitrogen it contained was recovered in the increased crop; when ammonia salts were applied, 52 per cent; when rape-cake was used, 50 per cent; and when a mixture of rape-cake and ammonia salts was used, 46 per cent.

It may be pointed out that the influence of season and climate on the composition of root crops is very great—greater, indeed, than on any other crop. Like oats, turnips grow better in Scotland than in England, the moister climate of the former country being more suitable for their maximum development, and hence the economy of maximum dressings in Scotland.

Norfolk Experiments.

In conclusion, a few words may be said on the Norfolk experiments, carried out under the direction of Mr Cooke for the purpose of ascertaining the best and most economical manure for mangels and swedes on different Norfolk soils. In most of these experiments it was found that superphosphate had not much effect in producing increase of crop in the case

of mangels; that the best nitrogenous manure was nitrate of soda; and that on the whole it was not economical to apply farmyard manure at the rate of more than 10 tons per acre. It was further found that, although either potash or common salt gave a decided increase in weight of roots, it was not necessary to give both these manures at once, either of them being about as effective as the other.

Mr Cooke recommends the following manures as best suited for mangels—viz., 2 cwt. nitrate, 3 cwt. common salt, and 2 cwt. superphosphate. Upon certain soils peculiarly adapted to mangels, and in warm localities where larger crops than 25 to 30 tons per acre are habitually grown, it would probably pay to increase or to double the above quantity of nitrate of soda. Ten tons of farmyard manure may, if preferred, be substituted for all or a part of the nitrate of soda, or may even be used in addition to it, according to the resources of the farmer in respect of it, and the return he desires to get from the dung in the first year of application or in future ones. It is best to apply the nitrate of soda in two instalments—half at the time of seeding, and half as a top-dressing immediately after the first hand-hoeing of the roots. A third dressing may often be given with advantage a month later.

Manure for Swedes.

As a complete and economical dressing for swedes in Norfolk, Mr Cooke recommends 3 to 4 cwt. super-

phosphate, 1 cwt. sulphate of ammonia, and $\frac{1}{2}$ cwt. of muriate of potash. Occasionally it may be found advisable to reduce the quantity of sulphate of ammonia, or to leave it out altogether; and in other cases the potash may be judiciously omitted. The entire mixture should be sown at the time of drilling the turnips. If farmyard manure is used—and if used it should be applied in a well-decomposed state—no other manure than 3 cwt. of superphosphate will be required.

Highland Society's Experiments.

Valuable experiments have been carried out on the subject of manuring of turnips by Dr A. P. Aitken, for the Highland and Agricultural Society of Scotland. The following are some of the results to be gathered from these experiments. The effect of a dissolved phosphate as compared with a ground phosphate is to produce a turnip of less feeding value. Superphosphate had a better effect when applied in April than when applied with the seed in June. It was further found that when the nitrogenous manure was given entirely in the form of nitrate of soda or sulphate of ammonia, the latter produced a denser and sounder turnip. Lastly, with regard to the application of potash, it was found that the best way was to apply it several months before sowing. The effect of potash manures is to increase the amount of turnips, but to retard the ripening of the bulbs. The effect of excessive potash manuring is to greatly injure the crop.

Manuring for rich Crops of Turnips.

In Dr Aitken's own words: "In order to grow a large and at the same time a healthy and nutritious crop of turnips, such a system of manuring or treatment of the soil, by feeding or otherwise, should be practised as will result in the general enriching and raising of the condition of the land, so that the crop may grow naturally and gradually to maturity. For that purpose a larger application of slowly acting manures, of which bone-meal may be taken as the type, is much better suited than smaller applications of the more quickly acting kind. A certain amount of quickly acting manure is very beneficial to the crop, especially in its youth; but the great bulk of the nourishment which the crop requires should be of the slowly rotting or dissolving kind, as uniformly distributed through the soil as possible."

Experiments by the Author.

Experiments by the author on turnip-manuring, carried out in different parts of the South and West of Scotland, showed that while farmyard manure is valuable in giving the crop a good start and bringing it well forward during the period of germination and early growth, by supplying a certain amount of easily assimilable plant-food, and in the case of dry weather attracting a quantity of moisture, its application in quantities of 20 or even 10 tons per

acre can scarcely be regarded as profitable, giving to farmyard manure a nominal value of a few shillings a ton. In these experiments slag proved itself a most valuable manure, indeed one of the most economical of all the manures experimented with. They further showed that heavy dressings with superphosphate, amounting to as much as 8 cwt. per acre, are, from an economical point of view, as a rule justifiable in Scotland; and that nitrate of soda and sulphate of ammonia possess practically equal value as a manure for turnips. In almost every one of the experiments the benefit of supplementing superphosphate with nitrogenous manure was shown. Potash was also found in many cases to be a thoroughly paying manure for the turnip crop, when it was applied along with nitrogen and phosphates; but when applied alone, far from exercising any appreciable benefit, it seemed to exert an injurious action.

POTATOES.

Potatoes are often classed along with the root crops, and in their manurial requirements they offer many points of similarity. Next to root crops, they may be said to make the most exhaustive demands on the soil, and therefore require a liberal general manuring. A point of importance in the manuring of potatoes is a good tilth in the soil, so as to enable a free expansion of the tubers to take place. They may be said to

grow best on deep warm soils; but, like roots, if liberally manured, they may be successfully grown on any kind of soil. Farmyard manure has long been regarded as specially valuable for the potato crop. In many parts of Scotland it is applied in enormous quantities, ranging from 20 to even 40 tons per acre. There can be little doubt that the value of farmyard manure, as well as other bulky manures, for the potato crop, is partly due to their mechanical influence on the soil. Potatoes are surface-feeders, and require their food in a readily available condition. It is found desirable, therefore, to supplement farmyard manure by readily available artificial manures. Potatoes repay the application of a mixed manure containing all the fertilising ingredients—nitrogen, phosphoric acid, and potash—better than most crops.

Highland Society's Experiments on Potatoes.

The nitrogen is, according to the Highland Society's experiments, best applied in the form of nitrate of soda. Sulphate of ammonia does not seem, when farmyard manure is also applied, to have an equally valuable effect, as it influences the size of the tuber, producing an undue proportion of small potatoes. When no farmyard manure is applied, however, sulphate of ammonia seems to have a good effect, especially in wet seasons.

With regard to the nature of the phosphatic manure to be applied, superphosphate is to be preferred.

Potatoes make large demands on potash, and consequently require potassic manures. In consequence of the fact that they receive large applications of farmyard manure, the necessity for adding potash in the form of artificial manures does not generally exist. Potash, if applied in too large quantities, has been found to exert a deleterious effect. We have already pointed out that muriate of potash tends to produce a waxy potato.

The Rothamsted Experiments with Potatoes.

The Rothamsted experimenters have very fully investigated the conditions of the manurial requirements of potatoes. In these experiments potatoes were grown year after year in the same field. It was found that the effect of mineral manures alone was greater than the effect of nitrogenous manures alone, and that of mineral manures phosphates, as a rule, had a better effect than potash; that under the action of the growth of potatoes a greater exhaustion of phosphates than of potash takes place in the soil; and lastly, that it is essential to have an abundant supply of the different fertilising ingredients in order to grow successful crops. In the Rothamsted experiments, the slow action of farmyard manure in supplying fertilising ingredients to the potatoes is strikingly demonstrated. Thus, although farmyard manure was applied at such a rate that more than 200 lb. of nitrogen were added to the soil, the result was inferior to that obtained

from the application of 86 lb. of nitrogen applied in the form of readily available artificial manure.

Effect of Farmyard Manure on Potatoes.

It may be said, in this respect, that the potato is less able to utilise the fertilising ingredients of farmyard manure than any other of the farm crops. Yet, despite this fact, farmyard manure has been found to be one of the best manures to apply. The reconciliation of these seemingly contradictory statements depends on the influence exerted by the farmyard manure on the mechanical condition of the soil, rendering it more porous and easily permeable to the surface-roots, upon the development of which the success of the crop so much depends. The beneficial effect of farmyard manure is also doubtless due to the increased temperature which large applications of it produce in a soil.

Sir J. Henry Gilbert, in his well-known Cirencester Lecture on the Growth of Potatoes, cites several examples of the manurial treatment of potatoes in different parts of the country. In Forfarshire, farmyard manure or stable manure is largely employed (at the rate of 12 to 14 tons, and in some cases even 20 tons per acre), and it is also largely supplemented by artificial manures. These latter are applied to the extent of about 10 cwt., and consist of superphosphate, dissolved bones, and potash salts. Six tons of potatoes are considered a fair crop. In

East Lothian the manuring is similar, with the exception that farmyard manure is applied in even larger quantities — 30 to 40 tons being often used. Sometimes potatoes are grown with artificial manures alone. It would seem that the usual crop of potatoes ranges from 4 to 8 tons per acre.

Manuring of Potatoes in Jersey.

The manuring of the potato crop, so largely grown in Jersey in the Channel Islands, is of interest. Potatoes are there grown two or three years, then corn, then grass for a few years, then potatoes again, no special rotation of crops being followed. Either farmyard manure or sea-weed is applied at the rate of 25 to 30 tons per acre, supplemented by 8 to 12 cwt. of artificial manures.

These statements show how prevalent the practice of heavily manuring the potato crop is.

The Influence of Manure on the Composition of the Potato.

The influence of manure on the composition of the potato crop is of much interest. Potatoes grown without manure, just as in the case of roots, are found to have a larger percentage of nitrogen than potatoes grown with manure. The effect of manuring, therefore, is to increase the proportion of starch, which is the most important constituent of the potato. Mineral manures have a greater effect in increasing

the percentage of starch than purely nitrogenous manures; but when used together, a still greater increase is obtained than when used singly. The effect of nitrogenous manures on the composition of roots and potatoes is thus seen to be similar. In the case of both crops the effect is to increase the proportion of the characteristic carbohydrate constituent, which in roots is sugar, and in potatoes starch. Potatoes, like roots, are also much influenced by the season. The effect of season and manuring on the potato disease is worthy of notice. Wet seasons are favourable to the development of the disease. It has been found that in a highly nitrogenous manured crop the proportion of diseased tubers is greater than in a non-manured crop.

LEGUMINOUS CROPS.

We have already referred to the manuring of crops of the leguminous class in discussing the manuring of meadows and permanent pasture. It was there pointed out that the tendency of certain manures was to encourage the growth of the leguminous plants of the herbage, while other manures had the effect of encouraging those of the gramineous class. It was pointed out that a manure which had this effect was potash, or any manure which owed its characteristic action to the fact that it supplied potash to the soil or set it free in the soil.

Leguminous Plants benefit by Potash.

This is one of the most important points to notice in manuring leguminous plants. Just as we can say that nitrogenous manures are specially beneficial to cereals, and phosphatic manures to roots, so potash is the special manure for leguminous crops.

Nitrogenous Manures may actually be hurtful.

But we have, further, an even more striking characteristic of leguminous crops to notice. We have seen that, with regard to the crops already discussed, while there are cases in which a fertilising ingredient may be of no value, or may positively exert a hurtful action on the crops, such cases are only exceptional. With regard to leguminous crops, however, we find that almost invariably they derive little or no benefit from the use of artificial nitrogenous manures. And this is all the more striking since they contain large quantities of nitrogen in their composition—twice as much as the cereals. The fact, which has long been noticed with regard to certain members of this class of plants, such as clover, that not only do they contain a large amount of nitrogen, but that by growing them on a soil the soil is largely enriched in this valuable fertilising constituent, has long waited for a satisfactory explanation, which at last has been forthcoming. The discovery that leguminous crops can

draw on the boundless store of nitrogen present in the air has done much to clear up the mystery. There are, however, other problems with regard to the growth of leguminous plants which still await solution.

Clover-sickness.

One of these is the fact that land on which a leguminous crop like clover has been growing for a number of years becomes unfit to support its growth any longer. Such a soil is termed "clover-sick"; and many have been the theories put forward to explain the phenomenon, but none of them can be regarded as satisfactory.

The knowledge that leguminous plants have the power of deriving their nitrogen from the air, furnishes us with an economical means of enriching our soils in nitrogen. By growing leguminous crops alternately with cereals, for example, the air should be made to furnish the necessary nitrogenous manure. As a matter of fact, modified forms of such a practice have long been in use—indeed the ordinary rotations of crops are, to a certain extent, adaptations of this practice.

Alternate Wheat and Beans Rotation.

An interesting experiment carried out at Rothamsted may be here cited which illustrates in a striking manner the truth of the above statement. Wheat and the leguminous crop beans were grown alter-

nately. It was found that almost as much wheat (containing nearly as much nitrogen) was yielded in eight crops of wheat so grown as was yielded by sixteen crops of wheat grown consecutively in an adjoining field.

The most commonly cultivated leguminous crops are clover, beans, and peas. Clover having been already discussed, we need only say a word or two on the manuring of beans and peas.

BEANS.

Beans do best on strong land, and, unlike some of the crops considered, do not require a particularly fine tilth. They are generally grown after cereals, and as a rule are sown in spring. More rarely, however, they are sown in autumn. Spring-sown beans take about seven months to come to maturity. They are much affected, like other crops, but to a greater extent, by the nature of the season—a wet season inducing an undue development of straw.

Manure for Beans.

In common practice the manure used for the bean crop is farmyard manure, applied to the soil in autumn after the harvest of the wheat, barley, or other cereal crop grown. So common is this practice, that the belief commonly exists that farmyard manure is necessary for a successful bean crop. But experi-

ments conducted at the Highland Society's Experiment Station at Pumpherston show that full crops of beans may be grown with the aid of artificial manures on soils which have received no application of farmyard manure for ten years.

Relative Value of Manurial Ingredients.

In the Appendix¹ will be found a table giving the results of manurial experiments with the nitrogenous, phosphatic, and potash manures on beans, carried out by Dr A. P. Aitken at the Highland Society's Experiment Station. From these experiments it will be seen that the application of phosphates and nitrogenous manures, either alone or together, exerted a comparatively small effect in increasing the yield of beans compared with that obtained with potash, either alone or combined with phosphates. As Dr Aitken says, "Without potash in the manure, the other two ingredients are of very little use, unless, indeed, the land be very rich in potash."

Gypsum.

Gypsum has a good effect on the bean crop, both on account of the lime it contains, and of its indirect action in setting free potash.

Superphosphate is a much better manure than insoluble phosphates, and similarly, in the few cases where nitrogenous manures are beneficial, the speediest acting are best. Hence nitrate of soda is to be pre-

¹ See Note I., p. 530.

ferred to other nitrogenous manures. When it is applied, it should be applied in small quantities. A slow-acting nitrogenous manure is positively injurious; so also, according to Dr Aitken, is nitrate of soda, applied as a top-dressing to the crop.

Of potash manures, the muriate seems to be more effective than the sulphate.

Effect of Manure on Composition of Crop.

Lastly, we may refer to the effect of manures on the composition of the crop. This is, on the whole, very slight, especially when compared with the effect manures exert on the composition of such crops as turnips or potatoes. It is the quantity and not the quality of the crop which the manure affects in the case of beans.

PEAS.

Peas are not grown to anything like the same extent as beans. As a rule, when they are cultivated it is along with beans, when they are necessarily manured in a similar manner. If grown alone, however, it may be well to point out that peas do best, unlike beans, on light, friable, chalky loam. When grown in clay they tend to develop an undue amount of straw. The effect of season on the crop is similar to that exerted on the bean crop. In conclusion, it may be pointed out that it is alleged that the effect of farmyard manure on peas is to force the straw.

In concluding this chapter a word or two may be said on the manuring of two other crops which are cultivated to a considerable extent in this country—viz., hops and cabbages.

HOPS.

The requirements of the hop crop in the matter of manures are rather singular. It has been pointed out that in the case of most crops quick-acting manures are to be preferred to slow-acting manures. With hops, however, the case is very different; for they require, and cannot be successfully cultivated without, slow-acting manures. Hops are especially benefited by bulky nitrogenous manures—such as shoddy, horn-meal, hide-scraps, hoofs, rape-dust, &c.; and it is only when quick-acting manures are applied along with such slow-acting manures that they will exercise their full influence. It is best to manure hops twice a-year, — in spring with farmyard manure, supplemented by a slow-acting nitrogenous manure, such as shoddy; and again in summer with a more quickly acting manure. The dressings applied to hops are enormous relatively to those used on other farm crops.

CABBAGES.

Cabbages belong to that class of crops known as gross feeders, to which any sort of manure, applied in almost any quantities, does not come amiss. Cab-

bage grow best on good loams with a well-drained porous subsoil, although they also do well on clay soils. The quantity of fertilising ingredients, especially potash, which a large crop of cabbage removes from the soil is very great. They consequently require large quantities of manure, and are especially benefited by saline manures—such as kainit and common salt—and liberal doses of nitrate of soda, which may be regarded as the most effective of manures for all the cabbage tribe. Farmyard manure may be applied with benefit in larger quantities than it would be applied to any other crop.

APPENDIX TO CHAPTER XXIII.

NOTE I. (p. 526).

EXPERIMENTS ON THE MANURING OF BEANS.

Experiments with beans carried out at the Highland and Agricultural Society's Experiment Station at Pumpherson, showing the effect of potash:—

No. of plots.	Kind of manure.	Bushels dressed grain, per acre.
27.	No manure	21½
12.	Phosphate (bone-ash)	51⅙
18.	Nitrate	61¼
21.	Phosphate and nitrate	51⅓
22.	<i>Potash</i>	26½
17.	<i>Potash</i> and phosphate	42⅓
10.	<i>Potash</i> , phosphate, and nitrate	45½
38.	<i>Potash</i> , phosphate, nitrate, and gypsum	51

CHAPTER XXIV.

ON THE METHOD OF APPLICATION AND ON THE
MIXING OF MANURES.

HAVING considered the manuring of the different crops, we may now pass on to the consideration of some points in the method of application and on the mixing of manures.

Equal Distribution of Manures.

A most important object in applying manures is to effect equal distribution of the manure in the soil. This is often, however, unusually difficult to do, especially in the case of artificial manures, where the quantity to be spread over a large area of the soil is extremely small. The difficulty in the case of farmyard or other very bulky manure is not so great. In order to overcome this difficulty in the case of artificial manures, it is often advisable to mix them with some such substance as sand, ashes, loam, peat, or salt. The manure is thus diluted in strength, and a very much larger bulk of substance is obtained

to work with. Circumstances must decide which of these substances to use. If the soil be a heavy clay, the addition of sand or ashes may have an important mechanical effect in improving its texture; while, on the other hand, if it be a light soil, the addition of peat may improve its mechanical condition. It must also be remembered that peat itself contains a large amount of nitrogen, and thus forms a manure of some value. In using loam or peat to mix with artificial manures, they should be first dried and then riddled; while if ashes be used, they should be previously reduced to a fine state. Wood-ashes, however, must be used with caution, and ought not to be mixed with ammoniacal manures, as they are apt to contain caustic alkali, which would tend to drive off the ammonia in a volatile state.

It has been recommended, in order to save trouble and effect equal distribution, that the manure to be applied should always be made up to the same amount, so that the farmer by experience may ascertain the rate at which to apply it. And here it may be well to say a word or two on the subject of mixing manures—a subject with which the farmer is not always so conversant as it is desirable in the interests of his own pocket he should be.

Mixing Manures.

It is to be feared that not unfrequently indiscriminate mixing may cause very serious loss in the most

valuable constituent of a manure. It may be well, therefore, to point out one or two of the causes of the loss that is apt to ensue on the mixing of different kinds of manures together.

As the subject depends for its clear comprehension on certain chemical elementary principles, it may be well for the benefit of non-chemical readers to state these pretty fully.

Risks of Loss in Mixtures.

The risks of loss which may occur from the mixing of artificial manures together may be of different kinds. One is the risk of actual loss of a valuable ingredient through volatilisation; another is the risk of the deterioration of the value of a mixture through change of the chemical state of a valuable ingredient. Undoubtedly the most common and most serious source of loss is the former. Of the three valuable manurial ingredients—nitrogen, phosphoric acid, and potash—only the first is liable to loss by volatilisation, and this generally only when the nitrogen is either in the form of ammonia or nitric acid.

Loss of Ammonia.

Ammonia, when uncombined, is a very volatile gas with a pungent smell, a property which enables its escape from a manure mixture to be very easily detected. It belongs to a class of substances which are known chemically as bases, and which have the power

of combining with acids and forming salts. Sulphate of ammonia is a salt formed—as its name indicates—by the union of the base, ammonia, with the acid, sulphuric acid. Now when ammonia unites with sulphuric acid and forms sulphate of ammonia, it is no longer volatile and liable to escape as a gas, but becomes “fixed,” as it is called.

Although most salts are more or less stable bodies—not liable to change—if left alone, and not submitted to a high temperature or chemical action, they can be easily decomposed if they are heated or brought into contact with some other substance which will give rise to chemical action. Sulphate of ammonia is a salt that is very easily decomposed. This is due to the fact that its base, ammonia, is very volatile, and not capable of being held very firmly by an acid, even by sulphuric, which is among the least volatile of all the common acids. If, therefore, sulphate of ammonia be heated above the boiling-point of water, or brought in contact with any other substance which will give rise to chemical action, it is easily decomposed. Now a salt may be acted upon by a base or an acid or another salt. When it is brought in contact with a base, if the base with which it is brought in contact be a stronger base than the base of the salt, the salt is decomposed, and a new salt is formed. The acid, in short, exchanges its old base for the new one.

Effect of Lime on Ammonia Salt.

This is exactly what takes place when the base lime comes in contact with an ammonium salt, such as sulphate of ammonia. The sulphuric acid exchanges its old base, ammonia, for the stronger base, lime, and sulphate of lime is formed, and ammonia is set free as a gas, and escapes and is lost. Sulphate of ammonia, or any substance in which there is an ammonia salt, must never be brought in contact with free lime, otherwise the ammonia will be lost, and should be harrowed in on chalky soils for this reason.

It is different entirely with gypsum—which is sulphate of lime—or phosphate of lime, both of which may be safely mixed with sulphate of ammonia without any danger of escape of ammonia. It follows from the above that a mixture which must on no account be tried is slag phosphate and sulphate of ammonia. This is because the slag phosphate contains a large percentage of free lime, which would at once, on being brought in contact with the sulphate of ammonia, decompose it, and cause the ammonia to be lost. For this same reason guano must not be mixed with slag. It is perhaps unnecessary, however, to warn one against so doing, as it is not likely such a mixture would be made, as the ratio of phosphoric acid to nitrogen in guanos is generally greater than is required. If it be desired to mix the slag with a quickly available form of nitrogen, nitrate of soda

is not liable to loss; although for other reasons it is not desirable to apply nitrate of soda along with the slag, as the former manure should be applied almost always as a top-dressing.

Loss of Nitric Acid.

The risks of the loss of nitrogen in the form of nitric acid, although not so great as they are in the case of ammonia, are still considerable. As nitric acid is not a base but an acid, what is to be avoided in mixing nitrates is bringing them in contact with any other manure which contains another free and stronger acid—as, for example, superphosphate. The free acid present in superphosphate has the tendency to drive out the nitric acid from the nitrate and usurp its place. The risk of loss of expulsion in the above cases is always augmented by the rise of temperature which invariably accompanies chemical action of any kind; and although the loss of nitrogen, in the form of nitric acid, caused by mixing superphosphate and nitrate of soda, might, under ordinary circumstances, amount to very little, yet, if the mixture were to be allowed to stand any time, and the temperature of the mass to be heightened, the loss which would undoubtedly then ensue would be considerable.

The nitrogen salt which it is safe to mix with superphosphate is sulphate of ammonia.

Reversion of Phosphates.

But, as has already been mentioned, there is another loss which may result from the mixing of manures. This is the deterioration of the value of an ingredient by reason of change of chemical condition. This is a source of loss that was little suspected a number of years ago, but it is now well known that superphosphate of lime, under certain conditions, is changed from its soluble to an insoluble form. We have already referred to the reversion of phosphate in the chapter on the Manufacture of Superphosphates.¹ It was there pointed out that reversion is often caused by the presence of iron and alumina or undissolved phosphate, and that the risk of reversion is therefore very much less in a well-made article, made from pure raw material, than in one made from a raw phosphate containing much iron and alumina. Superphosphates containing a large percentage of insoluble phosphates ought not to be kept too long before being used as a manure, otherwise much of the labour and expense involved in their manufacture will be lost by the reversion of their soluble phosphate. Further, it is highly inadvisable to mix superphosphates with basic slag, which contains a large percentage of both iron and free lime. Lastly, if it is desired to mix superphosphate with insoluble phosphate, the mixture ought to be made just previous to application.

¹ See p. 389.

Manurial Ingredients should be applied separately.

The question of applying manure in mixtures is one on which considerable difference of opinion may exist. For many reasons manures are often better applied in the unmixed condition. For example, a mixture of a quickly acting nitrogenous manure with a slowly acting phosphatic manure is not suitable. In such a case either the nitrogenous manure will be applied too long before it is required by the plant, and thus suffer from risk of loss, or the phosphatic manure will not be applied long enough before it is likely to be used. By applying manures in an unmixed condition the chances are that a more economical use of them is made than would otherwise be the case. On the other hand, while the application of the separate constituents may be desirable from the scientific point of view, it involves a considerable amount of extra trouble. Of course a further consideration is the desirability in many cases of having a complete manure. The above hints, therefore, on the risks of loss which exist in mixing manures, may be of service to the agricultural student.

CHAPTER XXV.

ON THE VALUATION AND ANALYSIS OF MANURES.

Value of Chemical Analysis.

THE value of a manure to the farmer depends on the proportion of *nitrogen*, *phosphoric acid*, and *potash* it contains, as well as—and this is hardly less important—the condition in which the ingredients are present. Since these facts can alone be determined by a chemical analysis, it is obvious that manures should always be purchased with a chemical analysis. It is unfortunate, however, that very often a chemical analysis, even when procured, is unintelligible. It may be of advantage, therefore, to say a word or two on the correct interpretation of the significance of the data furnished in the ordinary chemical analysis of manures.

Interpretation of Chemical Analysis.

The first thing that the farmer ought to look for in the analysis of a manure is the amount of nitro-

gen, phosphoric acid, and potash which the manure contains.

Nitrogen.

The percentage of nitrogen in a manure is generally stated as equal to its equivalent percentage of ammonia. Very often, indeed, in the older analyses, its equivalent of ammonia was alone stated. Now this statement does not necessarily imply that the nitrogen in a manure is actually present in the form of ammonia. Thus, for example, when it is stated in an analysis of bone-meal that it contains 3.5 per cent of nitrogen, equal to 4.20 per cent of ammonia, it is not to be inferred that bone-meal actually contains nitrogen in the form of ammonia. In point of fact the nitrogen is present in an insoluble, slowly available, organic form, which possesses a manurial value very inferior to that possessed by ammonia. This custom is a most unfortunate one, and is much to be regretted, as it is often liable to give rise to serious misunderstanding. It must be remembered, therefore, that an ordinary chemical analysis does not always specify the exact form in which nitrogen is actually present. It is nevertheless of importance for the farmer to know this, of which the nature of the manure analysed is generally a good indication. Unfortunately this is not shown in the case of *mixed* manures; and this constitutes one of the reasons why mixed manures are sometimes to be regarded with suspicion.

Phosphoric Acid.

The amount of phosphates present in a manure is usually stated in its analysis as so much phosphoric acid, while in a footnote the quantity of tricalcic (or ordinary bone) phosphate this amount is equivalent to is also given, this being the unit of valuation. When the phosphates are in a soluble condition they are stated as such, and at the same time a statement is made as to the quantity of tricalcic phosphate which would be required to furnish this amount by treatment with sulphuric acid. Thus, for example, in an analysis of a superphosphate of lime, the statement, *monocalcic phosphate, 17.3 per cent, equal to tricalcic phosphate rendered "soluble," 27.2 per cent*, means that it would require 27.2 per cent of tricalcic phosphate to furnish 17.3 per cent of soluble phosphate. Paradoxically enough, the former amount is called "*soluble*" phosphate, and such a superphosphate as the above would be described as containing 27.2 per cent of "*soluble*" phosphate.

Again, there are different forms of the so-called "*insoluble*" phosphates,¹ although they are often not distinguished in a chemical analysis. As we have already pointed out in the chapter on Basic Slag, phosphoric acid occurs in the slag in the form of tetrabasic phosphate of lime, although it is invariably stated in

¹ The term *insoluble phosphates* is an unfortunate one, as the word *insoluble* is purely relative in its significance. *Undissolved phosphates* would be a better term.

analysis as so much tricalcic phosphate. Then we have the so-called dibasic phosphate of lime, the form into which soluble phosphate in superphosphate is converted when "reversion" takes place. Hitherto it has not been customary in this country—although the custom is prevalent both on the Continent and in America—to distinguish in the analysis of a superphosphate the "reverted" phosphate from the undissolved phosphate; since the superior value of the former as a manure is not recognised in the manure-trade.¹

Importance of Mechanical Condition of Phosphate.

A further point to which it is desirable to draw attention is the *mechanical* condition of the different insoluble phosphates, which has an important influence on their value. A very wide difference, for example, exists between the value of phosphate of lime in such a manure as Malden guano and in the crystalline mineral apatite; although, chemically considered, the form in which the phosphoric acid is present is the same in both substances.

Potash.

Potash ought only to occur in a soluble form in manures. It is generally stated as so much potash, and in a footnote the equivalent amount of muriate

¹ The amount of "reverted" phosphate is estimated by the *ammonium citrate process*.

or sulphate of potash is given, the former being the more concentrated form of potash.

For purposes of reference a table will be found in the Appendix¹ giving some useful factors for converting different forms of nitrogen, phosphoric acid, and potash into one another.

Other Items in the Chemical Analysis of Manures.

The other items in the analysis of a manure are of comparatively secondary importance compared with those already named. Among them may be mentioned the *moisture*, the *insoluble matter*, and the *organic matter*. The amount of moisture and the amount of sand are two items of importance, since, if these are excessive, they afford presumption that the manure has been adulterated.

Fertilisers and Feeding Stuffs Act.

An Act was passed, and came into operation in January 1894, for the purpose of compelling every vendor of manure manufactured in this country or imported from abroad to give to the purchaser "an invoice stating the name of the article, and whether it is an artificially compounded article or not, and what is at least the percentage of the nitrogen, soluble and insoluble phosphates, and potash, if any, contained in the article, and this invoice shall have the

¹ See Note I., p. 553.

same effect as a warranty by the seller of the statements contained therein."

Different Methods of Valuing Manures.

The monetary value of a manure depends upon a number of more or less complicated commercial considerations, such as the questions of supply and demand, &c., which need not here be discussed, and which similarly regulate the monetary value of any other article of commerce.

"Unit" Value of Manurial Ingredients.

For the purpose of affording data for ascertaining the approximate value of a manure, tables have been drawn up giving what is called the "unit" value of the different manurial ingredients in various manures. This is obtained by dividing the market value of a manure per ton by the percentage of nitrogen, phosphoric acid, and potash it contains. Thus, for example, sulphate of ammonia of 97 per cent purity contains 25 per cent of ammonia, and at present (Dec. 1893) is valued at £13, 15s. per ton. In order to obtain the unit value of ammonia in sulphate of ammonia, we have only to divide £13, 15s. by 25, which gives us 11s. The value of such tables depends on the competence of those drawing them up, and they require to be subjected to constant revision. In the Appendix will be found two of these tables, taken from the

Transactions of the Highland and Agricultural Society of Scotland.'¹

Intrinsic Value of Manures.

But there is another way of valuing manures, and that is by attempting to ascertain what their intrinsic worth is in producing an increase in the returns of the crops. Of course it may be said that the intrinsic worth of manure affects directly its market value. This is doubtless true, but it is not the only factor in determining the market value of a manure.

Again, the intrinsic worth of a manure may be said to vary according to the soil to which it is applied and the climatic conditions. This being so, it is important for every farmer to try and ascertain for himself what the intrinsic value of different manures is on the soil of his farm; and this can only be done by carrying out manuring experiments for himself. This leads us to say a word or two on the important subject of

Field Experiments.

It is impossible that every farm should be able to support an experiment station for the purpose of carrying out elaborate experiments on the effect of different manures on different crops. Nevertheless it is possible and highly desirable for *every* farmer who is engaged in arable farming on any scale to carry out simple experiments for the purpose of

¹ See Note II., p. 554.

ascertaining the characteristic manurial requirements of his soil. This can be done at the expenditure of a little time and trouble, and should be carried out in the following way. The field on which it is desired to carry out the experiments should be divided into the requisite number of experiment plots. These, which may be the tenth, twentieth, or fortieth of an acre in extent, should be, if possible, on a level piece of ground—all of them equally free from the shelter of hedge or tree, and otherwise subjected to the same conditions. The nature of the soil of the different plots, as well as its past treatment, should be similar. It is desirable, in order to minimise experimental error as much as possible, to carry out the experiments in duplicate, or even triplicate. In the first place, there should be what is called a *nothing* plot—*i.e.*, a plot receiving no manure. The produce obtained from this plot, compared with the produce obtained from the other manured plots, will thus furnish data for estimating the respective amounts of increase obtained by different manures. One very simple kind of experiment is what is called the “seven-plot” test. It consists in testing the results obtained by using nitrogenous, phosphatic, and potash manures alone and in different combinations. Thus the plots would be manured respectively as follows:—

No.

1. Nothing plot.
2. Nitrogen.
3. Phosphates.
4. Potash.

No.

5. Nitrogen and phosphates.
6. Nitrogen and potash.
7. Phosphates and potash.

The subjects of other experiments might be such as the respective values of nitrogen in the different forms of sulphate of ammonia and nitrate of soda; phosphoric acid as superphosphate, and in an undissolved form as Thomas-slag; the relative importance of artificial and farmyard manure; the effect of manures applied at different times, as well as the effect of different quantities of the same manure; the most economical manures for different kinds of crops; and numerous other interesting problems connected with the practical application of manures.

In carrying out these experiments, care should be taken not to have the experimental plots *immediately* adjoining one another, as the manure applied to the one plot may, by soaking through the soil, affect the result on the adjoining plot. Especial note ought to be taken of the weather during the progress of the experiment. In order to make such experiments as valuable as possible, they ought to be continued year after year. At the conclusion of the experiment the produce obtained from each plot should be carefully weighed.

Educational Value of Field Experiments.

The educative value of such experiments is very great, and in this connection the remarks made by Mr F. J. Cooke, in a recent lecture delivered to the London Farmers' Club, are worthy of most careful consideration.

"Local experiments," he says, "teach the simple

principles which should determine the selection of manures, as well as scientific accuracy and method in their use. The value of experiments is thus brought home to men who would not go far to discover it; and the practice of a few simple trials upon a correct system, each on his own farm, is encouraged. That such trials may be conducted with very little expense to the farmer, or other difficult qualifications, and yet to his great practical advantage, I will venture to assert on the ground of my own personal experience. For some twenty years I have annually conducted private experiments on a very humble scale, and am not aware of any other separate practice which has been so useful to me. It has been pursued upon two light-land farms in different parts of the same county. Yet, in respect of manurial requirements, the proper treatment for one of them has differed so essentially from the other that a common practice upon both would have been simply ruinous."

Value of Manures deduced from Experiments.

Tables have been constructed for the purpose of showing the comparative value of different kinds of manures as deduced from such experiments, and may be fittingly compared with the tables giving the trade prices. We have already quoted some of these tables in the Appendix to the chapter on Mineral Phosphates. These tables show the relative intrinsic value of different forms of phosphatic manures. In

the Appendix¹ to this chapter tables showing the relative value of different kinds of nitrogenous and potash manures will be found.

Value of Unexhausted Manures.

A subject which has had much attention devoted to it of late years is the question of the value of unexhausted manures in the soil. In the Agricultural Holdings Act special provision is made for giving compensation to the out-going tenant of a farm for unexhausted manures in the soil. The Act has given rise to endless disputes between landlord and tenant, owing to the extreme difficulty of arriving at a satisfactory estimate of what the value of the unexhausted manures in reality is. The difficulty arises from the fact that we have not sufficient data available for guiding us in estimating this value, which further varies under different conditions. The fertilising ingredients of a soil are present in the soil for the most part in an inert condition, from which they are only slowly converted into an available form.

Potential Fertility of a Soil.

As indicating the total amount of the more important mineral ingredients present in a soil, it may be mentioned that it has been calculated, in the case of a poor sandy soil, *that the amount of potash it contains (provided it were in an available condition)* would

¹ See Note III., p. 556.

be sufficient to yield three or four average crops of potatoes; of phosphates, nineteen average crops; and of lime, seventy-three. But then only a very small amount of this fertilising matter is in a readily available form.

It is for this reason that artificial manures, although added in such small amounts, exercise so striking an influence in increasing plants' growth. Their effect, however, is to a large extent only of a temporary nature; and in attempting to assess the unexhausted value of a manure a year or two after its application, we must remember this fact.

Some manures are very speedily taken up by plants, and some are very easily washed out of the soil. Others, again, it would seem highly probable, have a tendency to become converted into a more or less inert condition after a while. This remark may be especially applied to the fertilising constituents (chiefly nitrogen) in farmyard manure.¹ The whole question, however, is little understood. One or two points may be drawn attention to. In the first place, it may be safely affirmed that little direct effect can be expected from such quickly available and easily soluble forms of nitrogenous manures as nitrate of soda and sulphate of ammonia a year after application. Potash and phosphates, on the other hand, may exercise an effect for a considerably longer period; and what the length of this period may be will de-

¹ See Chapter on Farmyard Manure, p. 271.

pend on their amount and condition. Thus it is not likely that superphosphate will have much effect more than two years after application. On the other hand, such manures as bones, basic slag, and farmyard manure may exert an appreciable influence for a number of years. How long exactly, it is wellnigh impossible to say, the rate at which they are applied and the nature of the soil having an important influence.

Tables of Value of Unexhausted Manures.

Numerous tables have been drawn up for the purpose of guiding farmers in estimating this unexhausted value at different periods after application, and in the case of different manures. Such tables, as a rule, furnish only very rough approximations, and are little better than mere guess-work. Still more complicated is the attempt to assess the manurial value of foods consumed by the stock of the farm. Lawes and Gilbert have devoted much attention to the elucidation of this difficult question, and have drawn up most elaborate and valuable tables, furnishing data for calculating unexhausted manure value in the case of commonly used foods. These tables are given in the Appendix.¹ In them will be found the manurial value of different cattle-foods, calculated on the basis of numerous experiments carried out at Rothamsted.

¹ See Note IV., p. 557.

Thus these experiments have demonstrated that, on an average, probably not more than *one-tenth* of the nitrogen, phosphoric acid, and potash a food contains is removed from the food in its passage through the animal system. The exact amount will obviously depend on a variety of conditions, referred to already in a previous chapter.¹

In explanation of these tables, it may be pointed out that Table I. gives the total quantities of the three fertilising ingredients in various foods; while Table II. shows the proportion retained in the animal body and the proportion voided in the manure, as well as the manurial value of the food, assuming that it exercises its full theoretical effect. As this, however, is never fully realised, it is necessary to make some deduction. The deduction suggested by the Rothamsted experimenters, on the basis of their wide experience, is 50 per cent for food consumed within the last year. That is to say, the manurial value of food consumed during the last year is *only one-half its theoretical value*. For food consumed within the last year but one, they suggest a deduction of one-third of the allowance for last year; while for food consumed three years back, a deduction of one-third from this latter sum should be made; and so on for whatever number of years, down to eight, may be taken.

¹ See Chapter on Farmyard Manure, pp. 224-236.

APPENDIX TO CHAPTER XXV.

NOTE I. (p. 543).

USEFUL FACTORS FOR CALCULATING THE PERCENTAGE OF IMPORTANT MANURIAL INGREDIENTS IN A MANURE INTO THEIR DIFFERENT COMPOUNDS. (From the 'Transactions of the Highland and Agricultural Society.')

Amount of	Multiplied by	Gives corresponding amount of
Nitrogen	1.214	Ammonia.
"	6.3	Albuminoid matter.
Ammonia . . . .	.824	Nitrogen.
"	3.882	Sulphate of ammonia.
"	3.147	Muriate of ammonia.
"	3.706	Nitric acid.
"	5.0	Nitrate of soda.
Potash (anhydrous) . .	1.85	Sulphate of potash.
"	1.585	Muriate of potash.
Phosphoric acid (anhydrous)	2.183	Phosphate of lime.
" "	1.4	Biphosphate.
" "	1.648	Soluble phosphate.
Soluble phosphate . .	1.325	Phosphate of lime.
Biphosphate	1.566	"
Lime	1.845	"
"	1.786	Carbonate of lime.
Chlorine	1.648	Chloride of sodium.

NOTE II. (p. 545).

UNITS TO BE USED IN DETERMINING THE COMMERCIAL VALUE OF MANURES.

For Season 1893.

Items to be valued.	Guanos.		Scrap manures.		Bone-meal.		Steamed bone-flour.	Dissolved or vitriolated bones.	Superphosphates.	Dissolved compounds.		
	Ichaboe.	Peruvian (riddled).	Fish guano.	Frey Bentos guano.	a.	b.	a.			From	To	Average.
Phosphates—												
Dissolved . . .	2/-	2/-	1/5	1/6	1/4	1/3	1/5	2/6	1/11	2/-	2/6	2/3
Undissolved—	16/-	17/2	10/-	11/6	10/-	9/6	10/-	1/6	...	1/3	1/9	1/6
Ammonia . . .	...	3/6	...	...	...	...	...	11/6	...	10/-	12/-	11/-
Potash . . .	...	...	...	...	...	...	...	...	...	3/4	3/8	3/6
Prices per ton, March 1893—												
From . . .	250/-	230/-	130/-	150/-	105/-	100/-	95/-	95/-	45/-	...	...	...
To . . .	270/-	290/-	150/-	140/-	115/-	110/-	110/-	110/-	60/-	...	...	...

NOTE II.—*continued.*

CASH PRICES OF DIFFERENT MANURES, MARCH 1893.

MANURES.	Guarantee.	Price per ton.	Unit.
	Per cent.	£ s. d.	
Sulphate of ammonia, 97 per cent . .	24 Am.	11 10 0	Am. = 9/7
Nitrate of soda, 95 per cent . . .	19 "	10 5 0	" = 10/9
Castor-cake dust	5.5 "	3 10 0	" = 12/9
Horn-dust	15 "	8 10 0	" = 11/4
Dried blood	15 "	8 0 0	" = 10/7
Muriate of potash, 80 per cent . .	50 Pot.	8 15 0	Pot. = 3/6
Sulphate of potash, 50 per cent . .	27 "	5 5 0	" = 3/10
Kainit, 23 per cent	12 "	2 0 0	" = 3/4
Nitrate of potash, 73 per cent . .	{ 14 Am. } { 40 Pot. }	14 10 0	{ Am. = 10/ Pot. = 3/9
Ground Charleston phosphate . .	57 Phos.	3 0 0	Phos. = 1/
Belgian phosphate	50 "	2 5 0	" = 0/11
Thomas-slag (fine) Scotch . . .	30 "	1 16 0	" = 1/2
" " " English	37 "	2 3 0	" = 1/2
Phosphatic guano	{ 67 " } { 1 Am. }	5 0 0	{ " = 1/4 Am. = 10/

NOTE III. (p. 549).

TABLES SHOWING RELATIVE MANURIAL VALUE OF NITROGEN
AND POTASH IN DIFFERENT SUBSTANCES.*Wolff, 1893.*

Nitrogen in form of ammonia and nitrates, and easily decomposable organic compounds, as dried blood, flesh-meal, meat-meal, Peruvian guano, and as urate	100
" in fine steamed bone-meal, fish-guano, oilcakes, and better kinds of artificial guano	85
" in fine bone-meal and horn-meal	77
" in coarse bones and horn-shavings, woollen refuse, farmyard manure, and poudrette	61

American, 1892.

" in ammonia salts	100
" as nitrates	86
" in dry and fine-ground fish, meat, and blood	91
" in cotton-seed meal, and castor pomace	86
" in fine bone and tankage	86
" in medium bone and tankage	68
" in coarser bone and tankage	43
" in hair and horn-shavings, and coarse fish scrap	40
Potash as high-grade sulphate, and in forms free from muriates (or chlorides)	100
" as muriate	82

Professor Wagner has drawn up, from numerous experiments, the relative manurial values of different nitrogenous manures, which he rates as follows :—

Nitrate of soda	100
Sulphate of ammonia	90
Blood-meal, horn-meal, and green vegetable matter	70
Finely ground steamed bone-meal, fish-meal, and meat-meal guano	60
Farmyard manure	45
Shoddy	30
Leather-meal	20

NOTE IV. (p. 551).

TABLE I.—AVERAGE COMPOSITION, PER CENT AND PER TON,
OF CATTLE-FOODS.

No.	FOODS.	PER CENT.					PER TON.		
		Dry Matter.	Nitro- gen.	Mineral Matter (Ash).	Phos- phoric Acid.	Potash.	Nitrogen.	Phos- phoric Acid.	Potash.
		per cent.	per cent.	per cent.	per cent.	per cent.	lb.	lb.	lb.
1	Linseed . . .	90.00	3.60	4.00	1.54	1.37	80.64	34.50	30.69
2	Linseed-cake . . .	88.50	4.75	6.50	2.00	1.40	106.40	44.80	31.36
3	{ Decorticated cotton-cake }	90.00	6.60	7.00	3.10	2.00	147.84	69.44	44.80
4	Palm-nut-cake . . .	91.00	2.50	3.60	1.20	0.50	56.00	26.88	11.20
5	{ Undecorticated cotton-cake }	87.00	3.75	6.00	2.00	2.00	84.00	44.80	44.80
6	Cocoa-nut-cake . . .	90.00	3.40	6.00	1.40	2.00	76.16	31.36	44.80
7	Rape-cake . . .	89.00	4.90	7.50	2.50	1.50	109.76	56.00	33.60
8	Peas . . .	85.00	3.60	2.50	0.85	0.96	80.64	19.04	21.50
9	Beans . . .	85.00	4.00	3.00	1.10	1.30	89.60	24.64	29.12
10	Lentils . . .	88.00	4.20	4.00	0.75	0.70	94.08	16.80	15.68
11	Tares (seed) . . .	84.00	4.20	2.50	0.80	0.80	94.08	17.92	17.92
12	Indian corn . . .	88.00	1.70	1.40	0.60	0.37	38.08	13.44	8.29
13	Wheat . . .	85.00	1.80	1.70	0.85	0.53	40.32	19.04	11.87
14	Malt . . .	94.00	1.70	2.50	0.80	0.50	38.08	17.92	11.20
15	Barley . . .	84.00	1.65	2.20	0.75	0.55	36.96	16.80	12.32
16	Oats . . .	86.00	2.00	2.80	0.60	0.50	44.80	13.44	11.20
17	Rice-meal ¹ . . .	90.00	1.90	7.50	(0.60)	(0.37)	42.56	(13.44)	(8.29)
18	Locust-beans ¹ . . .	85.00	1.20	2.50	..	..	26.88	..	..
19	Malt-combs . . .	90.00	3.90	8.00	2.00	2.00	87.36	44.80	44.80
20	Fine pollard . . .	86.00	2.45	5.50	2.90	1.46	54.88	64.96	32.70
21	Coarse pollard . . .	86.00	2.50	6.40	3.50	1.50	56.00	78.40	33.60
22	Bran . . .	86.00	2.50	6.50	3.60	1.45	56.00	80.64	32.48
23	Clover-hay . . .	83.00	2.40	7.00	0.57	1.50	53.76	12.77	33.60
24	Meadow-hay . . .	84.00	1.50	6.50	0.40	1.60	33.60	8.96	35.84
25	Pea-straw . . .	82.50	1.00	5.50	0.35	1.00	22.40	7.84	22.40
26	Oat-straw . . .	83.00	0.50	5.50	0.24	1.00	11.20	5.38	22.40
27	Wheat-straw . . .	84.00	0.45	5.00	0.24	0.80	10.08	5.38	17.92
28	Barley-straw . . .	85.00	0.40	4.50	0.18	1.00	8.96	4.03	22.40
29	Bean-straw . . .	82.50	0.90	5.00	0.30	1.00	20.16	6.72	22.40
30	Potatoes . . .	25.00	0.25	1.00	0.15	0.55	5.60	3.36	12.32
31	Carrots . . .	14.00	0.20	0.90	0.09	0.28	4.48	2.02	6.27
32	Parsnips . . .	16.00	0.22	1.00	0.19	0.36	4.93	4.26	8.06
33	Swedish turnips . . .	11.00	0.25	0.60	0.06	0.22	5.60	1.34	4.93
34	Mangel-wurzels . . .	12.50	0.22	1.00	0.07	0.40	4.93	1.57	8.96
35	Yellow turnips ¹ . . .	9.00	0.20	0.65	(0.06)	(0.22)	4.48	(1.34)	(4.93)
36	White turnips . . .	8.00	0.18	0.68	0.05	0.30	4.03	1.12	6.72

¹ In the case of neither rice-meal, locust-beans, nor yellow turnips have records of ash analyses been found. For rice-meal the same percentages of phosphoric acid and potash as in Indian corn, and for yellow turnips the same as in swedes, are provisionally adopted; but in all the Tables the assumed results are given in parentheses. For locust-beans no figure has been assumed, and the columns are left blank.

TABLE II.—LAWES' & GILBERT'S TABLES

No.	DESCRIPTION OF FOOD.	Fattening Increase in Live Weight (Oxen or Sheep).		NITROGEN.						
				In Food.		In Fattening Increase (at 1.27 per cent).		In Manure.		
		Food to 1 In-crease.	In-crease per ton of Food.	Per cent.	Per ton.	From 1 ton of Food.	Per cent of total consumed.	Total remaining for Manure.	Nitrogen equal Ammonia.	Value of Ammonia at 6 per lb.
			lb.	%	lb.	lb.	%	lb.	lb.	£ s.
1	Linseed . . .	5.0	448.0	3.60	80.64	5.69	7.06	74.95	91.0	2 5
2	Linseed-cake . . .	6.0	373.3	4.75	106.40	4.74	4.45	101.66	123.4	3 1
3	{ Decorticated cotton-cake }	6.5	344.6	6.60	147.84	4.38	2.96	143.46	174.2	4 7
4	Palm-nut-cake . . .	7.0	320.0	2.50	56.00	4.06	7.25	51.94	63.1	1 11
5	{ Undecorticated cotton-cake }	8.0	280.0	3.75	84.00	3.56	4.24	80.44	97.7	2 8
6	Cocoa-nut-cake . . .	8.0	280.0	3.40	76.16	3.56	4.67	72.60	88.2	2 4
7	Rape-cake . . .	(10)	(224)	4.90	109.76	2.84	2.59	106.92	129.8	3 4
8	Peas . . .	7.0	320.0	3.60	80.64	4.06	5.03	76.58	93.0	2 6
9	Beans . . .	7.0	320.0	4.00	89.60	4.06	4.53	85.54	103.9	2 11
10	Lentils . . .	7.0	320.0	4.20	94.08	4.06	4.32	90.02	109.3	2 14
11	Tares (seed) . . .	7.0	320.0	4.20	94.08	4.06	4.32	90.02	109.3	2 14
12	Indian corn . . .	7.2	311.1	1.70	38.08	3.95	10.37	34.13	41.4	1 0
13	Wheat . . .	7.2	311.1	1.80	40.32	3.95	9.80	36.37	44.2	1 2
14	Malt . . .	7.0	320.0	1.70	38.08	4.06	10.66	34.02	41.3	1 0
15	Barley . . .	7.2	311.1	1.65	36.96	3.95	10.69	33.01	40.1	1 0
16	Oats . . .	7.5	298.7	2.00	44.80	3.79	8.46	41.01	49.8	1 4
17	Rice-meal . . .	7.5	298.7	1.90	42.56	3.79	8.91	38.77	47.1	1 3
18	Locust-beans . . .	9.0	248.9	1.20	26.88	3.16	11.76	23.72	28.8	0 14
19	Malt-combs . . .	8.0	280.0	3.90	87.36	3.56	4.08	83.80	101.8	2 10
20	Fine pollard . . .	7.5	298.7	2.45	54.88	3.79	6.91	51.09	62.0	1 11
21	Coarse pollard . . .	8.0	280.0	2.50	56.00	3.56	6.35	52.44	63.7	1 11
22	Bran . . .	9.0	248.9	2.50	56.00	3.16	5.64	52.84	64.2	1 12
23	Clover-hay . . .	14.0	160.0	2.40	53.76	2.03	3.78	51.73	62.8	1 11
24	Meadow-hay . . .	15.0	149.3	1.50	33.60	1.90	5.65	31.70	38.5	0 19
25	Pea-straw . . .	16.0	140.0	1.00	22.40	1.78	7.95	20.62	25.0	0 12
26	Oat-straw . . .	18.0	124.4	0.50	11.20	1.58	14.11	9.62	11.7	0 5
27	Wheat-straw . . .	21.0	106.7	0.45	10.08	1.36	13.49	8.72	10.6	0 5
28	Barley-straw . . .	23.0	97.4	0.40	8.96	1.24	13.84	7.72	9.4	0 4
29	Bean-straw . . .	22.0	101.8	0.90	20.16	1.29	6.39	18.87	22.9	0 11
30	Potatoes . . .	60.0	37.3	0.25	5.60	0.47	8.39	5.13	6.2	0 3
31	Carrots . . .	85.7	26.1	0.20	4.48	0.33	7.37	4.15	5.0	0 2
32	Parsnips . . .	75.0	29.9	0.22	4.93	0.38	7.71	4.55	5.5	0 2
33	Swedish turnips . . .	109.1	20.5	0.25	5.60	0.26	4.64	5.34	6.5	0 3
34	Mangel-wurzels . . .	96.0	23.3	0.22	4.93	0.30	6.09	4.63	5.6	0 2
35	Yellow turnips . . .	133.3	16.8	0.20	4.48	0.21	4.69	4.27	5.2	0 2
36	White turnips . . .	150.0	14.9	0.18	4.03	0.19	4.71	3.84	4.7	0 2

V.—continued.

CALCULATING UNEXHAUSTED VALUE OF MANURES.

PHOSPHORIC ACID.						POTASH.								Total original Manure value per ton of Food consumed.
In Food.		In Fattening Increase at (0.86 per cent).		In Manure.		In Food.		In Fattening Increase at (0.11 per cent).		In Manure.				
Per cent.	Per ton.	From 1 ton of Food.	Per cent of total consumed.	Total re-main-ing for Man-ure.	Value at 3d. per lb.	Per cent.	Per ton.	From 1 ton of Food.	Per cent of total consumed.	Total re-main-ing for Man-ure.	Value at 2½d. per lb.			
%.	lb.	lb.	%.	lb.	s. d.	%.	lb.	lb.	%.	lb.	s. d.			
1.54	34.50	3.85	11.16	30.65	7 8	1.37	30.69	0.49	1.60	30.20	6 3	2 19 5		
2.00	44.80	3.21	7.17	41.59	10 5	1.40	31.36	0.41	1.31	30.95	6 5	3 18 6		
3.10	69.44	2.96	4.26	66.48	16 8	2.00	44.80	0.38	0.85	44.42	9 3	5 13 0		
1.20	26.88	2.75	10.23	24.13	6 0	0.50	11.20	0.35	3.13	10.85	2 3	1 19 10		
2.00	44.80	2.41	5.38	42.39	10 7	2.00	44.80	0.31	0.69	44.49	5 11	3 5 4		
1.40	31.36	2.41	7.68	28.95	7 3	2.00	44.80	0.31	0.69	44.49	9 3	3 0 7		
2.50	56.00	1.93	3.45	54.07	13 6	1.50	33.60	0.25	0.74	33.35	6 11	4 5 4		
0.85	19.04	2.75	14.44	16.29	4 1	0.96	21.50	0.35	1.63	21.15	4 5	2 15 0		
1.10	24.64	2.75	11.16	21.89	5 6	1.30	29.12	0.35	1.20	28.77	6 0	3 3 5		
0.75	16.80	2.75	16.37	14.05	3 6	0.70	15.68	0.35	2.23	15.33	3 2	3 1 4		
0.80	17.92	2.75	15.35	15.17	3 9	0.80	17.92	0.35	1.95	17.57	3 8	3 2 1		
0.60	13.44	2.68	19.94	10.76	2 8	0.37	8.29	0.34	4.10	7.95	1 8	1 5 1		
9.85	19.04	2.68	14.08	16.36	4 1	0.53	11.87	0.34	2.86	11.53	2 5	1 8 7		
0.80	17.92	2.75	15.35	15.17	3 9	0.50	11.20	0.35	3.13	10.85	2 3	1 6 8		
0.75	16.80	2.68	15.95	14.12	3 6	0.55	12.32	0.34	2.76	11.98	2 6	1 6 1		
0.60	13.44	2.57	(19.12)	10.87	2 8	0.50	11.20	0.33	2.94	10.87	2 3	1 9 10		
(0.60)	(13.44)	2.57	(19.12)	(10.87)	(2 8)	(0.37)	(8.29)	0.33	(4.00)	(7.96)	(1 8)	(1 7 10)		
..	..	2.14	..	..	..	..	..	0.27	..	..	..	...
2.00	44.80	2.41	5.38	42.39	10 7	2.00	44.80	0.31	0.69	44.49	9 3	3 10 9		
2.90	64.96	2.57	3.96	62.39	15 7	1.46	32.70	0.33	1.01	32.37	6 9	2 13 4		
3.50	78.40	2.41	3.07	75.99	19 0	1.50	33.60	0.31	0.92	33.29	6 11	2 17 9		
3.60	80.64	2.14	2.65	78.50	19 8	1.45	32.48	0.27	0.83	32.21	6 8	2 18 5		
0.57	12.77	1.38	10.81	11.39	2 10	1.50	33.60	0.18	0.54	33.42	7 0	2 1 3		
0.40	8.96	1.28	14.28	7.68	1 11	1.60	35.84	0.16	0.45	35.68	7 5	1 8 7		
0.35	7.84	1.20	15.31	6.64	1 8	1.00	22.40	0.15	0.67	22.25	4 8	0 18 10		
0.24	5.38	1.07	19.89	4.31	1 1	1.00	22.40	0.14	0.63	22.26	4 8	0 11 7		
0.24	5.38	0.92	17.10	4.46	1 1	0.80	17.92	0.12	0.67	17.80	3 8	0 10 1		
0.18	4.03	0.84	20.84	3.19	0 9	1.00	22.40	0.11	0.49	22.29	4 8	0 10 1		
0.30	6.72	0.88	13.10	5.84	1 5	1.00	22.40	0.11	0.49	22.29	4 8	0 17 7		
0.15	3.36	0.32	9.52	3.04	0 9	0.55	12.32	0.04	0.32	12.28	2 7	0 6 5		
0.09	2.02	0.22	10.89	1.80	0 5	0.28	6.27	0.03	0.48	6.24	1 4	0 4 3		
0.19	4.26	0.26	6.10	4.00	1 0	0.36	8.06	0.03	0.37	8.03	1 8	0 5 5		
0.06	1.34	0.18	13.43	1.16	0 4	0.22	4.93	0.02	0.41	4.91	1 0	0 4 7		
0.07	1.57	0.20	12.74	1.37	0 4	0.40	8.96	0.03	0.34	8.93	1 10	0 5 0		
(0.06)	(1.34)	0.14	(10.78)	(1.20)	(0 4)	(0.22)	(4.93)	0.02	(0.34)	(4.91)	(1 0)	(0 3 11)		
0.05	1.12	0.13	11.61	0.99	0 3	0.30	6.72	0.02	0.30	6.70	1 5	0 4 0		

CHAPTER XXVI.

THE ROTHAMSTED EXPERIMENTS.

REFERENCE has been so repeatedly made in the preceding pages to the Rothamsted experiments on manures, that it may form a fitting conclusion to the present treatise to give a short account of these famous experiments.

In describing these experiments, the author has remarked elsewhere ¹ “that, in respect of their wide scope, dealing as they have done with almost every department of farming, the elaborate care and accuracy with which they have been carried out, the length of time they have been in progress, and, lastly, in respect of the important bearing their results have had on agricultural practice, these famous experiments may be justly described as unrivalled by any other similar ones.”

Started on a small scale in 1837 by Sir John (then Mr) Lawes, they were placed on a systematic basis in 1843, in which year Sir John Lawes associated with

¹ See Sir John Bennet Lawes, Bart., and the Rothamsted Experiments. By C. M. Aikman. (‘Scottish Farmer’ Office, Glasgow.)

himself Sir (then Dr) J. Henry Gilbert. They have thus been in progress for a period of fifty years—a fact which was celebrated* a few months ago by the presentation of numerous congratulatory addresses from various learned and agricultural societies to the distinguished investigators, and the erection of a memorial granite slab at Rothamsted. What increases the feeling of gratitude due to Sir John Lawes by the agricultural community, is the fact that the entire expense of conducting these experiments has been borne by himself, and he has further most generously handed over to the nation a large sum of money and a certain area of land for carrying them on in perpetuity.

Nature of Experiments on Crops and Manures.

The earliest systematic experiments were on turnips, and since then almost every common crop has been experimented on. Table I. (p. 562) is a list of the different experiments, with their duration, area, and number of plots.

Soil of Rothamsted.

Before describing the more striking results of these experiments, it may be advisable to say that the elevation of the land at Rothamsted is about 400 feet above sea-level; that the average rainfall is about 28 inches per annum; and that the surface-soil is a heavy loam, and the subsoil a stiff clay, resting on chalk.

TABLE I.—LIST OF ROTHAMSTED FIELD EXPERIMENTS.

CROPS.	Duration.	Area.	Plots.
	Years.	Acres.	
Wheat (various manures) . .	50	11	34 (or 37)
Wheat alternated with fallow . .	42	1	2
Wheat (varieties)	15	4-8	about 20
Barley (various manures) . .	42	4 $\frac{1}{4}$	29
Oats (various manures) . .	10 ¹	0 $\frac{3}{4}$	6
Beans (various manures) . .	32 ²	1 $\frac{1}{4}$	10
Beans (various manures) . .	27 ³	1	5
Beans, alternated with wheat . .	28 ⁴	1	10
Clover (various manures) . .	29 ⁵	3	18
Various leguminous plants . .	16	3	18
Turnips (various manures) . .	28 ⁶	8	40
Sugar-beet (various manures) . .	5	8	41
Mangel-wurzel (various manures)	18	8	41
Total root crops . .	51		
Potatoes (various manures) . .	18	2	10
Rotation (various manures) . .	46	3	12
Permanent grass (various manures)	38	7	22

¹ Including one year fallow.

² Including one year wheat and five years fallow.

³ Including four years fallow.

⁴ Including two years fallow.

⁵ Clover, twelve times sown (first in 1848), eight yielding crops, but four of these very small, one year wheat, five years barley, twelve years fallow.

⁶ Including barley without manure three years (eleventh, twelfth, and thirteenth seasons).

WHEAT EXPERIMENTS.

The first experiments we shall refer to are those on *wheat*, since they are among the oldest, and their results the most striking of any.

Unmanured Plots.

Wheat has been continuously grown year after year on three plots for fifty years, without the application of any manure whatever.

We shall first give the results of the first eight years as illustrating the effect of season, which accounts for the irregular results obtained. But for the difference in seasons, we should expect to find a steady decrease in the amount of produce; and this is shown in taking the average of groups of years, as we shall do in the next table.

WHEAT GROWN CONTINUOUSLY ON SAME LAND (unmanured).

TABLE II.—(a.) *Results of first Eight Years* (1844 to 1851).

Year.	Bushels.	Year.	Bushels.
1844 . .	15	1849 . .	$19\frac{1}{4}$
1845 . .	$23\frac{1}{4}$	1850 . .	$15\frac{7}{8}$
1846 . .	18	1851 . .	$15\frac{7}{8}$
1847 . .	$16\frac{7}{8}$		
1848 . .	$14\frac{3}{4}$	Average of 8 years	<u>$17\frac{3}{8}$</u>

TABLE III.—(b.) *Results of subsequent Forty Years* (1852 to 1891).

	Grain (bushels).	Weight per bushel.	Straw (cwts.)
20 years (1852–1871) . .	$14\frac{1}{2}$	$57\frac{5}{8}$	13
20 " (1872–1891) . .	$11\frac{1}{2}$	$58\frac{3}{4}$	$8\frac{5}{8}$
40 " (1852–1891) . .	13	$58\frac{1}{4}$	$10\frac{5}{8}$
49th season (1891) . .	$9\frac{3}{8}$	$59\frac{1}{2}$	$7\frac{1}{2}$

It is interesting to notice the comparatively slight decrease which has taken place in the yield of wheat during these fifty years. With such wide variations, due to season, it is extremely difficult, as Sir J. Henry Gilbert has pointed out, to estimate rate of decline due to exhaustion. Excluding the very bad seasons, this may be reckoned at from one-fourth to one-third of a bushel per acre per annum. *The return of the first year is 15 bushels, while the yield of the forty-ninth season is $9\frac{3}{8}$ bushels.* The average of the returns

obtained during these fifty years is really in excess of the average yield of the principal wheat-producing countries in the world. This is truly a most astounding result.

The next experiments we shall describe are those on the influence of farmyard manure on the wheat crop when grown continuously.

TABLE IV.—WHEAT GROWN CONTINUOUSLY WITH FARMYARD MANURE (14 tons per annum).

			Bushels.	Weight per bushel (lb.)	Straw (cwt.s.)
8 years (1844-1852)	.	.	28	...	...
20 " (1852-1871)	.	.	35 $\frac{7}{8}$	60	33 $\frac{7}{8}$
20 " (1872-1891)	.	.	33 $\frac{1}{2}$	60 $\frac{3}{8}$	31 $\frac{3}{8}$
40 " (1852-1891)	.	.	34 $\frac{7}{8}$	60 $\frac{1}{4}$	32 $\frac{5}{8}$

It will be seen from the above results, which contain merely a selection from a very much greater number of experiments, that farmyard manure gives as good an average over the forty years as most of the artificial mixtures do. That this is due to the nitrogen it contains, is strikingly illustrated by the fact that mixed mineral manures alone give less than half the return, and also by the fact that ammonia salts alone give a return twice as great as mineral mixtures; while, lastly, the mixture of mineral manures and ammonia salts gives but a slight increase over that obtained with ammonia salts alone.

The remaining results, selected from a much larger number, need no comment, and we shall give them in tabular form.

TABLE V.—WHEAT GROWN CONTINUOUSLY WITH ARTIFICIAL MANURES, FARMYARD MANURE,
AND UNMANURED.

Average of Forty Years (1852-91).

MANURES PER ACRE PER ANNUM.	PRODUCE PER ACRE—AVERAGE PER ANNUM.														
	Dressed grain.							Total straw.							
	Quantity.							Weight per bushel.							
	20 years, 1852-71.	40 years, 1852-91.	bush.	20 years, 1852-71.	40 years, 1852-91.	lb.	20 years, 1852-71.	40 years, 1852-91.	lb.	20 years, 1852-71.	40 years, 1852-91.	cwt.	20 years, 1852-71.	40 years, 1852-91.	cwt.
Farmyard manure, 14 tons per annum since 1843	35½	34½	bush.	60	60½	lb.	38½	38½	38½	37½	37½	cwt.	32½	32½	cwt.
Unmanured continuously	14½	11½	13	57½	58½	58½	13	13	13	8½	8½	10½	10½	10½	10½
Mixed mineral manures † and 3½ cwt. superphosphate	17	12½	15	58½	59	59	13	13	13	9½	9½	12½	12½	12½	12½
Mixed mineral manures, 3½ cwt. superphosphate, 200 lb. ammonium salts	26½	21½	24½	59½	60	59½	24½	24½	24½	19½	19½	21½	21½	21½	21½
Mixed mineral manures and 3½ cwt. superphosphate, 600 lb. ammonium salts	38½	34½	36½	59	60	59½	41½	41½	41½	39½	39½	40½	40½	40½	40½
Mixed mineral manures, 3½ cwt. superphosphate, 275 lb. nitrate of soda	36½	34	35½	58½	59½	59½	41½	41½	41½	37½	37½	39½	39½	39½	39½
275 lb. nitrate of soda	26	19½	22½	56½	56½	56½	28½	28½	28½	18½	18½	20½	20½	20½	20½
400 lb. ammonium salts every year since 1845	22½	19	22½	58	57½	57½	21	21	21	16½	16½	20½	20½	20½	20½
400 lb. ammonium salts, 3½ cwt. superphosphate	28	22½	25½	57½	58	58	26½	26½	26½	21	21	23½	23½	23½	23½
Mineral manure, 3½ cwt. superphosphate, 400 lb. ammonium salts in autumn	31½	29½	30½	59½	60	59½	31½	31½	31½	28½	28½	29½	29½	29½	29½

† By the term mixed mineral manures is meant a mixture of mineral fertilisers, not including phosphates.

TABLE VI.—EXPERIMENTS ON THE GROWTH OF BARLEY FOR FORTY YEARS, 1852-91.

MANURES PER ACRE PER ANNUM.	PRODUCE PER ACRE—AVERAGE PER ANNUM.									
	Dressed grain.					Total straw.				
	Quantity.					Weight per bushel.				
	20 years, 1852-71.	20 years, 1872-91.	40 years, 1852-91.	20 years, 1852-71.	20 years, 1872-91.	40 years, 1852-91.	20 years, 1852-71.	20 years, 1872-91.	40 years, 1852-91.	20 years, 1872-91.
Unmanured continuously	bush.	bush.	bush.	lb.	lb.	lb.	cwt.	cwt.	cwt.	cwt.
3½ cwt. superphosphate of lime	20	13½	16½	52½	51½	52	11½	6½	9½	9½
Mixed mineral manures	25½	17½	21½	53½	53	53½	13½	8½	10½	10½
Mixed mineral manures, 3½ cwt. superphosphate	22½	13½	18	53	51½	52½	12½	7	9½	9½
200 lb. ammonium salts	27½	17½	22½	53½	52	53	14½	8½	11½	11½
200 lb. ammonium salts, 3½ cwt. superphosphate	32½	25½	29	52½	52	52	18½	13½	16	16
200 lb. ammonium salts, 3½ cwt. superphosphate	47	38½	42½	53½	52½	52½	27½	20½	23½	23½
200 lb. ammonium salts, mixed mineral manures	35	27½	31½	52½	52½	52½	20½	15½	18	18
Manures, 3½ cwt. superphosphate of lime	46½	40½	43½	54	54½	54	28½	23½	25½	25½
275 lb. nitrate of soda	37	28½	32½	52	52½	52	22½	15½	19	19
275 lb. nitrate of soda, 3½ cwt. superphosphate	49½	42½	45½	53½	53½	53½	30½	23½	27	27
275 lb. nitrate of soda, mixed mineral manures	37½	29½	33½	52½	52½	52½	23½	17½	20½	20½
275 lb. nitrate of soda, mixed mineral manures, 3½ cwt. superphosphate	49½	41½	45½	53½	54	53½	32½	24½	28½	28½
1000 lb. rape-cake	45½	37½	41½	53½	53½	53½	26½	20	23½	23½
1000 lb. rape-cake, 3½ cwt. superphosphate	46½	40	43½	53½	54½	54½	28½	21½	24½	24½
1000 lb. rape-cake, mixed mineral manures	43½	35½	39½	53½	54½	54	27½	19½	23½	23½
1000 lb. rape-cake, mixed mineral manures, and 3½ cwt. superphosphate	47½	39	43½	53½	54½	53½	29½	21½	25½	25½
Farmyard manure, 14 tons every year	48½	49	48½	54½	54½	54½	28½	29½	29½	29

TABLE VII.

EXPERIMENTS ON THE GROWTH OF OATS, 1869-78.

MANURES PER ACRE PER ANNUM.	AVERAGE PER ANNUM. 5 YEARS, 1869-73.		
	Dressed grain.		Total straw.
	Quantity.	Weight per bushel.	
Unmanured	Bushels. 19 $\frac{7}{8}$	lb. 33 $\frac{3}{4}$	cwt. 10 $\frac{3}{8}$
200 lb. sulphate potash, 100 lb. sulphate soda, 100 lb. sulphate magnesia, and 3 $\frac{1}{2}$ cwt. superphosphate of lime	24 $\frac{1}{2}$	35	13 $\frac{3}{8}$
400 lb. ammonium salts	47	35 $\frac{7}{8}$	28 $\frac{1}{2}$
400 lb. ammonium salts, 200 lb. sulphate potash, 100 lb. sulphate soda, 100 lb. sulphate magnesia, and 3 $\frac{1}{2}$ cwt. super- phosphate	59	37	41 $\frac{1}{8}$
550 lb. nitrate of soda	47 $\frac{1}{8}$	35 $\frac{1}{2}$	27 $\frac{1}{2}$
550 lb. nitrate of soda, 200 lb. sulphate potash, 100 lb. sulphate soda, 100 lb. sulphate magnesia, and 3 $\frac{1}{2}$ cwt. super- phosphate	57 $\frac{1}{2}$	35 $\frac{3}{4}$	35
AVERAGE PER ANNUM. 4 YEARS, 1874-78.			
Unmanured	Bushels. 13 $\frac{3}{4}$	lb. 31 $\frac{1}{4}$	cwt. 6
200 lb. sulphate potash, 100 lb. sulphate soda, 100 lb. sulphate magnesia, and 3 $\frac{1}{2}$ cwt. superphosphate of lime	13 $\frac{1}{8}$	31 $\frac{5}{8}$	6 $\frac{1}{8}$
200 lb. ammonium salts	28 $\frac{7}{8}$	33 $\frac{1}{4}$	14 $\frac{1}{8}$
200 lb. ammonium salts, 200 lb. sulphate potash, 100 lb. sulphate soda, 100 lb. sulphate magnesia, and 3 $\frac{1}{2}$ cwt. super- phosphate	38	35 $\frac{1}{2}$	20
275 lb. nitrate of soda	26 $\frac{3}{8}$	31 $\frac{5}{8}$	11 $\frac{1}{8}$
275 lb. nitrate of soda, 200 lb. sulphate potash, 100 lb. sulphate soda, 100 lb. sulphate magnesia, and 3 $\frac{1}{2}$ cwt. super- phosphate	28 $\frac{1}{2}$	34 $\frac{1}{8}$	14

TABLE VIII.—EXPERIMENTS ON
Fifteen Seasons, 1856–70

Plot.	STANDARD MANURES.	SERIES 1. Standard manures only.	
		Roots.	Leaves.
		Tons. cwt.	Tons. cwt.
1	Farmyard manure, 14 tons	6 4	0 17
2	Farmyard manure, 14 tons, and superphosphate . . .	6 7	0 16
3	Without manure, 1846, and since	0 11	0 3
4	Superphosphate, each year; sulphate potash, soda, and magnesia, 1856-60	2 16	0 8
5	Superphosphate, each year	2 12	0 9
6	Superphosphate, each year; sulphate potash, 1856-60 . .	2 7	0 7
7	Superphosphate, each year; sulphate, potash, and 36½ lb. ammonium salts, 1856-60	2 12	0 7
8	Unmanured 1853, and since; previously part unmanured: part superphosphate	1 3	0 4

Note.—Sulphate of ammonia is estimated to contain 23 per cent ammonia, and muriate of ammonia of commerce; and the mixture is estimated to contain 25 per cent ammonia. The crops of Series 2 from 1856-60, were estimated to contain 25 per cent ammonia.

¹ The crops of 1859 and 1860 failed, and were ploughed in; but as the manure was applied to the crops, the average produce is calculated as for fifteen years—that is, the produce of 1856-70.

TABLE IX.—EXPERIMENTS ON
Average of Sixteen Seasons, 1876-92

Plot.	STANDARD MANURES.	SERIES 1. Standard manures only.	
		Roots.	Leaves.
		Tons. cwt.	Tons. cwt.
1	Farmyard manure, 14 tons	16 6	2 17
2	Farmyard manure, 14 tons, and 3½ cwt. superphosphate . . .	16 12	2 18
3	Without manure, 1846, and since	4 9	1 8
4	3½ cwt. superphosphate, 500 lb. sulphate of potash, and 400 lb. mixed mineral manure	5 8	1 1
5	3½ cwt. superphosphate	5 0	1 1
6	3½ cwt. superphosphate, and 500 lb. sulphate of potash . .	4 9	0 18
7	3½ cwt. superphosphate, 500 lb. sulphate of potash, and 36½ lb. ammonium salts	5 17	1 3

ROOT CROPS—SWEDISH TURNIPS.

Roots and Leaves carted off the Land.

SERIES 2.		SERIES 3.		SERIES 4.		SERIES 5.	
Standard manures, and cross-dressed with 5 years, 1855-60, 320 lb. sulphate, and 328 lb. nitric acid.		Standard manures, and cross-dressed with 5 years, 1855-60, 200 lb. ammonium salts.		Standard manures, and cross-dressed with 5 years, 1855-60, 200 lb. ammonium salts, and 2000 lb. sawdust.		Standard manures, and cross-dressed with 5 years, 1855-60, 2000 lb. sawdust.	
10 years, 1861-70, 550 lb. nitrate soda.		10 years, 1861-70, 400 lb. ammonium salts.		10 years, 1861-70, 400 lb. ammonium salts, and 2000 lb. rape-cake.		10 years, 1861-70, 2000 lb. rape-cake.	
Roots.	Leaves.	Roots.	Leaves.	Roots.	Leaves.	Roots.	Leaves.
Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.
7 9	1 2	8 8	1 4	8 16	1 9	8 0	1 4
7 13	1 3	8 5	1 5	8 14	1 9	7 16	1 2
0 19	0 4	0 13	0 3	3 6	0 14	3 8	0 13
5 2	0 16	4 12	0 14	6 12	1 5	5 8	0 17
4 13	0 18	3 16	0 15	5 16	1 7	5 0	0 19
4 11	0 14	4 5	0 13	6 6	1 2	5 3	0 16
4 13	0 14	4 12	0 14	6 15	1 4	5 9	0 17
1 13	0 5	1 2	0 5	3 19	0 18	3 14	0 19

biurate of ammonia 27 per cent. Ammonium salts, in each case, equal parts sulphate and ammonia. The 328 lb. nitric acid (sp. gr. 1.35) mixed with sawdust, and used as guano=50 lb. ammonia.

were applied, and there would be accumulation within the soil for the succeeding the thirteen years is, in each case, divided by 15.

MANGEL-WURZEL.

Manures per Acre per Annum.

SERIES 2.		SERIES 3.		SERIES 4.		SERIES 5.	
Standard manures, and cross-dressed with 10 years, 1861-70, 550 lb. nitrate of soda.		Standard manures, and cross-dressed with 10 years, 1861-70, 400 lb. ammonium salts.		Standard manures, and cross-dressed with 10 years, 1861-70, 2000 lb. rape-cake, and 2000 lb. ammonium salts.		Standard manures, and cross-dressed with 10 years, 1861-70, 2000 lb. rape-cake.	
Roots.	Leaves.	Roots.	Leaves.	Roots.	Leaves.	Roots.	Leaves.
Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.
22 11	4 2	22 3	5 7	24 11	6 1	23 7	4 6
23 12	4 14	21 8	5 6	23 12	6 1	23 1	4 6
13 7	3 4	6 14	2 18	10 11	3 17	11 2	3 0
12 17	3 15	16 2	3 0	24 18	5 7	20 4	3 9
15 13	3 5	8 10	3 1	11 7	4 2	12 3	3 2
15 15	2 18	14 6	2 16	21 6	5 7	16 14	2 15
16 0	3 1	16 3	3 0	21 6	5 9	17 10	3 3

TABLE X.—EXPERIMENTS WITH DIFFERENT MANURES ON PERMANENT MEADOW-LAND.

Thirty-six Years, 1856-91.

MANURES PER ACRE PER ANNUM.	PRODUCE PER ACRE, WEIGHED AS HAY.					
	Average per annum, 20 years, 1856-75 (1st crops only).			Average per annum, 16 years, 1876-91 (1st and 2d crops).		
	10 years, 1856-65.	10 years, 1866-75.	20 years 1856-75.	1st crops.	2d crops.	Total.
Unmanured continuously	cwt. 22 $\frac{1}{2}$	cwt. 20	cwt. 21 $\frac{1}{4}$	cwt. 18	cwt. 8 $\frac{1}{2}$	cwt. 26 $\frac{1}{2}$
3 $\frac{1}{2}$ cwt. superphosphate of lime	23 $\frac{1}{4}$	21 $\frac{1}{4}$	22 $\frac{1}{4}$	18	9	27 $\frac{1}{2}$
3 $\frac{1}{2}$ cwt. superphosphate of lime, and 400 lb. ammonium salts	33 $\frac{7}{8}$	30 $\frac{1}{2}$	32 $\frac{1}{4}$	30 $\frac{3}{4}$	10 $\frac{1}{2}$	41 $\frac{1}{4}$
400 lb. ammonium salts	30 $\frac{1}{2}$	22	26 $\frac{1}{4}$	18 $\frac{1}{4}$	10 $\frac{1}{8}$	27 $\frac{3}{8}$
275 lb. nitrate of soda, 3 $\frac{1}{2}$ cwt. superphosphate, and mixed mineral manure }	45 $\frac{1}{4}$	47 $\frac{5}{8}$	46 $\frac{1}{2}$	41 $\frac{1}{8}$	12 $\frac{1}{8}$	53 $\frac{1}{4}$
275 lb. nitrate of soda	34 $\frac{1}{4}$	33 $\frac{1}{2}$	33 $\frac{3}{8}$	30 $\frac{1}{8}$	10	40 $\frac{1}{8}$

TABLE XI.—EXPERIMENTS ON THE GROWTH OF POTATOES.
Average of Five Seasons, 1876–80.¹

Plot.	MANURES PER ACRE PER ANNUM.	PRODUCE PER ACRE—TUBERS.					
		Good.		Small.		Diseased.	
		Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Total.
1	Unmanured	1 18	0 6½	0 6½	0 2½	2 6½	2 6½
2	Farmyard manure (14 tons)	3 19½	0 7½	0 7½	0 6½	4 13½	4 13½
3	Farmyard manure (14 tons), and 3½ cwt. superphosphate	4 9½	0 8	0 8	0 8½	5 6½	5 6½
4	Farmyard manure (14 tons), 3½ cwt. superphosphate, and 550 lb. nitrate of soda	5 8	0 7	0 7	0 19½	6 14½	6 14½
5	400 lb. ammonium salts	1 19½	0 7½	0 7½	0 3½	2 10½	2 10½
6	550 lb. nitrate of soda	2 11½	0 6½	0 6½	0 5½	3 4	3 4
7	400 lb. ammonium salts, 3½ cwt. superphosphate, 300 lb. sulphate potash, 100 lb. sulphate soda, 100 lb. sulphate magnesia	5 14½	0 8½	0 8½	0 14½	6 17½	6 17½
8	550 lb. nitrate of soda, 3½ cwt. superphosphate, 300 lb. sulphate potash, 100 lb. sulphate soda, 100 lb. sulphate magnesia	5 19½	0 7½	0 7½	0 19½	7 6½	7 6½
9	3½ cwt. superphosphate	3 0¾	0 8	0 8	0 4½	3 13½	3 13½
10	3½ cwt. superphosphate, 300 lb. sulphate potash, 100 lb. sulphate soda, and 100 lb. sulphate magnesia	3 4½	0 6½	0 6½	0 4½	3 15½	3 15½

¹ In each year the tops were spread on the respective plots.

TABLE XII.—EXPERIMENTS ON THE GROWTH OF POTATOES—*continued*.
Average of Twelve Seasons, 1881-92.

Plot.	MANURES PER ACRE PER ANNUM.	PRODUCE PER ACRE—TUBERS.							
		Good.		Small.		Diseased.		Total.	
		Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.	Tons. cwt.
1	Unmanured in 1876, and each year since	1	3 $\frac{3}{4}$	0	3 $\frac{3}{4}$	0	0 $\frac{1}{4}$	1	7 $\frac{3}{4}$
2	Unmanured in 1882, and since; previously farmyard manure (14 tons)	2	14 $\frac{1}{4}$	0	4 $\frac{3}{4}$	0	2	3	1
3	Farmyard manure (14 tons) alone, 1883, and since; previously 3 $\frac{1}{2}$ cwt. superphosphate also	4	3 $\frac{1}{4}$	0	4 $\frac{1}{4}$	0	4 $\frac{1}{2}$	4	12
4	Farmyard manure (14 tons) alone, 1883, and since. In 1882 and previously 3 $\frac{1}{2}$ cwt. superphosphate, and in 1881 and previously 550 lb. nitrate of soda also	4	6 $\frac{1}{4}$	0	4 $\frac{1}{2}$	0	4 $\frac{3}{4}$	4	15 $\frac{1}{2}$
5	400 lb. ammonium salts	1	2 $\frac{3}{4}$	0	4 $\frac{3}{4}$	0	0 $\frac{1}{2}$	1	8
6	550 lb. nitrate of soda	1	17 $\frac{3}{4}$	0	3 $\frac{3}{4}$	0	0 $\frac{3}{4}$	2	21
7	400 lb. ammonium salts, 3 $\frac{1}{2}$ cwt. superphosphate, 300 lb. sulphate of potash, and 200 lb. mixed mineral manure	5	6 $\frac{3}{4}$	0	5	0	4 $\frac{1}{2}$	5	16 $\frac{1}{4}$
8	550 lb. nitrate of soda, 3 $\frac{1}{2}$ cwt. superphosphate, 300 lb. sulphate of potash, and 200 lb. mixed mineral manure	5	7 $\frac{1}{2}$	0	4 $\frac{1}{4}$	0	3 $\frac{3}{4}$	5	15 $\frac{1}{2}$
9	3 $\frac{1}{2}$ cwt. superphosphate	2	17 $\frac{3}{4}$	0	3 $\frac{1}{4}$	0	1	3	2
10	3 $\frac{1}{2}$ cwt. superphosphate, 300 lb. sulphate of potash, and 200 lb. mixed mineral manure	3	21	0	3 $\frac{1}{4}$	0	14	3	6 $\frac{3}{4}$

INDEX.

- ABRAUM salts, 421.
 Absorptive power of soils for water, 67, 98; how to increase, 74.
 Acidity in soils neutralised by lime, 458.
 Acids fixed by soil, 58.
 Adametz on organisms in soil, 92.
 Adulteration of guano, 318-320.
 Africa, guano from, 298, 328.
 Agricultural chemistry, historical introduction to, 3-61; Liebig's researches on, 23-32; Liebig's services to, 31.
 Agronomy, 56.
 Air, ammonia in, 48, 118; nitrates in, 118; nitrites in, 118; nitrogen in, 116; organic nitrogen in, 118.
 Aitken, Dr, experiments with basic slag, 413—with beans, 526, 530; on germ-life in bones, 368; on manuring of turnips, 515.
 Albert, Heinrich, on solubility of basic slag, 409.
 Albite, composition of, 103.
 Albuminates, 460.
 Albuminoids, in plants, 491; of milk, nitrification in, 182; phosphorus in, 205.
 Algerian phosphate, 379.
 Algoa Bay, guano deposits at, 328.
 Alkalies, in cow-dung, 226, 227—cow-urine, 230—horse-dung, 226, 227—horse-urine, 230—pig-dung, 226, 227—pig-urine, 230—sheep-dung, 226, 227—sheep-urine, 230.
 Alkalinity necessary for nitrification, 172.
 Alumina, in ash of plants, 55; compounds, reversion caused by, 388, 400; salts, in *salinas*, 335.
 America, virgin soils of, 133.
 American farming, 86.
 Amides, 501.
 Ammonia, absorbed by soil, 81; amount dissolved in rain, 49; amount in air, 48; amount in soil, 127; amount supplied to soil by rain, 155; converted into nitrates in soil, 50; converted into nitrous acid, 167; fixed by soil, 58; from decomposition of farmyard manure, 258; from gas-works, 353; lost in mixing manures, 533; relation of, to plants, 48-50; salts, most easily nitrifiable, 191; salts of, in farmyard manure, 257; sulphate of, 352-358; value of, as a manure, 352.
 Ammonium chloride in Chincha guano, 305.
 Ammonium-magnesium phosphate in Chincha guano, 305.
 Ammonium oxalate in concretionary nodules, 328.
 Ammonium phosphate, in Chincha guano, 305; in concretionary nodules, 328.
 Ammonium sulphate, 352-358; in Chincha guano, 305; in concretionary nodules, 328.
 Ammonium sulphocyanate, 355.
 Ammonium urate in concretionary nodules, 328.
 Amphibole, potash in, 220.

- Analysis, of manures, 539-554 ; of soils, value of, 90.
- Anderson, Dr, analyses of minerals by, 103, 105-107 ; on nitrogen in soil, 121, 124.
- Angamos, guano from, 301, 329.
- Animals, phosphoric acid in, 205 ; potash in, 205 ; solid excreta of, 224 ; urine of, 228.
- Apatite, Canadian, 201, 374 ; composition of, 210 ; most abundant form of phosphoric acid, 200 ; varieties of, 200.
- Application of manures, 474-492.
- Arabian coast, guano deposits on, 328.
- Arable soil, absorptive power of, 98.
- Arbrohlos Island guano, 309.
- Arendt, experiments on oats by, 503.
- Aristotelian doctrine of chemical elements, 4.
- Artificial soil, 54.
- Aruba phosphate, 308, 328, 379.
- Ash, constituents of plants, 53-55 ; of rye, phosphoric acid in, 204 ; of wheat, phosphoric acid in, 204 ; of farmyard manure, composition of, 287, 288.
- Ashes, an adulterant of guano, 319 ; mixed with manures, 532.
- Asia, guano from, 298.
- Asparagin, nitrification in, 182.
- Atacama, nitrate of soda deposits at, 342.
- Atmosphere, ammonia in, 48, 81 ; relation of, to plants, 39.
- Atwater on nitrogen in plants, 44.
- Augite, 105.
- Australia, guano from, 298 ; virgin soils of, 133.
- Avenine in oats, 503.
- Aves guano, 309, 328 ; phosphoric acid in, 330.
- Bacilli, 94.
- Bacon, Lord, on salt as a manure, 469.
- Bacteria, in soil, 92 ; different classes of, 93-96.
- Baker Island guano, 309, 328 ; phosphoric acid in, 330.
- Ballestas, guano from, 302, 327 ; nitrogen in, 329 ; phosphoric acid in, 329.
- Barilla, potash in, 420.
- Barley, farmyard manure not suited for, 497 ; fertilising ingredients removed from soil by, 485 ; manurial constituents in, 282 ; manuring of, 495, 498 ; nitrogen removed in crop of, 145 ; Norfolk experiments on, 497 ; period of growth of, 495 ; period of ripening of, 495 ; Rothamsted experiments on growth of, 566 ; soils suited for, 496 ; uniform manuring of, 497.
- Barley soils, amount of nitrates and nitrogen in, 158.
- Barley-straw, composition of, 238 ; manurial constituents in, 282.
- Basalt, phosphoric acid in, 202, 210.
- Bases fixed by soil, 58.
- Basic-ammonium phosphate incretionary nodules, 328.
- Basic process of steel-smelting, 400.
- Basic silicates, 103.
- Basic slag, 401-417 ; after-effects of, 412 ; application of, method of, 416—rate of, 414 ; compared with other manures, 410-414 ; composition of, 404, 417 ; Darmstadt experiments with, 410 ; discovery of value of, 403 ; manufacture of, 401 ; preparation of, processes for, 406 ; relative activity of, 411 ; soils best suited for, 414 ; solubility of, 408 ; Wagner's experiments with, 408-413.
- Bat guano, 320, 325 ; nitrogen in, 325 ; phosphoric acid in, 325.
- Beans, fertilising ingredients removed from soil by, 485 ; good effect of gypsum on, 526 ; manurial constituents in, 282 ; manuring of, 525-527 ; phosphorus in, 205 ; relative value of manurial ingredients to, 526 ; source of nitrogen, 153.
- Bean-straw, manurial constituents in, 282.
- Beatson, General, experiments of, with Peruvian guano, 301.
- Beddington meadows, irrigation at, 432.
- Bedfordshire, coprolites from, 374.
- Belgian phosphate, 377.
- Berthelot on sources of plant-nitrogen, 42.
- Biological properties of soil, 92-96.
- Blood corpuscles, potash in, 217.

- Blood, dried, 424; composition of, 424; manure for sugar-cane, 425; potash in, 217, 219; rate of nitrification in, 192; source of nitrogen, 152; suited for horticulture, 425.
- Bohemia, phosphoric acid removed from, 206.
- Bolivia, guano deposits at, 327.
- Bollaert on nitrate deposits, 333.
- Bone-ash, 369; composition of, 372.
- Bone-black, 369; composition of, 372.
- Bone-char, 369; composition of, 372.
- Bone-dust, 360.
- Bone-meal, 361, 364; composition of, 371; condition of nitrogen in, 540.
- Bone-phosphate, 385.
- Bones, 359-372; action of, 365; boiled, 361; bruised, 361; capable of nitrification, 182; collected in Britain, 353, 362; composition of, 362, 371; compound, 372; crops suited for, 368; dissolved, 368, 371; early use of, 359; fermentation of, 361; floated, 365; forms of, 360; grinding of, 365; imports of, 151; inorganic matter in, 363; nitrogen in, 151; organic matter in, 363; putrefaction of, 365, 366; raw, 361; source of nitrogen, 151; treatment of, 364.
- Bonnet, Charles, discovery of source of plant's carbon by, 11.
- Boracic acid in *salinas*, 335.
- Bordeaux phosphate, 379.
- Boussingault, on dry matter in horse-manure, 243; early researches of, in agricultural chemistry, 21; experiments by, on nitrification, 185, 198; on excrements of pig, 250; on nitrates in guano, 304; on nitrogen in plants, 41, 42; on nitrogen in soil, 124; on nitrogen in excreta, 234; on nitrogen lost during fermentation, 245.
- Bracken-fern, analyses of, 283; as litter, 241.
- Bran, manurial constituents in, 282.
- Bretschneider on sources of plant-nitrogen, 42.
- Brewers' grain, manurial constituents in, 282.
- Bromine in ash of plants, 55.
- Browse Island guano, 309, 328; phosphoric acid in, 330.
- Brüstlein and Peters on fixation of bases and acids by soil, 59.
- Buckland, Dr, discovery of coprolites by, 373.
- Buckwheat absorbs ammonia, 352.
- Bull River, phosphates from, 376.
- Cabbages, benefited by saline manures, 529; manuring of, 528-529; soils suited for, 529.
- Caird, Sir James, experiments by, with Peruvian guano, 301.
- Calcareous earth, absorptive power of, 98; stones, phosphoric acid in, 211.
- Calcium phosphate in Chincha guano, 305.
- Calcium sulphate in concretionary nodules, 328.
- Caliche*, composition of, 342; occurrence of, 341.
- California, guano deposits at, 328.
- Cambridgeshire, coprolites from, 373.
- Cameron, Sir Charles, on assimilation of urea by plants, 46.
- Canadian apatite, 201, 374.
- Cape Vert guano, phosphoric acid in, 330.
- Carbolic acid, action of, on nitrifying organisms, 177.
- Carbon, fixation of, by plants, 37; in plants, discovery of source of, 11.
- Carbon bisulphide, effect of, on nitrification, 166, 176.
- Carbonate of ammonia formed in fermentation of dung, 247, 258.
- Carbonic acid, absorbed by plants, 12—by soil, 81; in ash of plants, 55; oxidation of, by bacteria, 95; produced in decomposition of farmyard manure, 258.
- Carbonising-works, ammonia from, 353, 358.
- Carburetted hydrogen, produced in decomposition of farmyard manure, 258.
- Caribbean phosphates, 379.
- Carnallite, 420.
- Carolina phosphate, 376.
- Carrots, manurial constituents in, 282.
- Catacombs, bones from, 360.
- Catch-cropping, 138, 489.

- Cattle foods, average composition of, 557.
- Caustic lime, 453.
- Cereals, manuring of, 493-504; nitrogenous manures benefit, 494; potash in, 217; silicates absorbed by, 494; value of nitrate of soda as manure for, 346.
- Chalk, an adulterant of guano, 319; lias, phosphoric acid in, 211.
- Charcoal, a filter for sewage, 437.
- Charleston phosphate, 376.
- Chemical analysis of manures, interpretation of, 539; value of, 539.
- Chemical composition of soil, 87-92.
- Cheshire, bones used in, 360.
- Chesterfield Island guano, 309.
- Chili and Peru, chief source of nitrate of soda, 162.
- Chincha Island guano, 302, 303, 327; composition of, 305; nitrogen in, 329; phosphoric acid in, 329.
- Chipana, guano deposits at, 327.
- Chlorapatite, composition of, 210.
- Chlorine in ash of plants, 55.
- Chloroform prevents nitrification, 166, 176.
- Chlorophyll, organisms destitute of, 169; produced by nitrate of soda, 347; relation of, to fixation of carbon by plants, 37.
- Chuca, 341.
- Citrate of ammonia, solubility of phosphates in, 408.
- Clay, absorptive power of, 68; analysis of, 107; grey, evaporation of water from, 99; loamy, evaporation of water from, 99; sandy, absorptive power of, 98—evaporation of water from, 99; soils, benefited by basic slag, 414—puddling in, 455; stiffish, evaporation of water from, 99; strong absorptive power of, 98.
- Clover-hay, fertilising ingredients removed from soil by, 486; manurial constituents in, 282; manuring of, 522.
- Clover-sickness, 522.
- Coal, nitrogen in, 353.
- Coke-works, ammonia from, 353, 358.
- Colloids, 491.
- Colour of soil, 80; difference in temperature due to, 80.
- Columbia, guano deposits at, 327.
- Composts, 113, 445-448; farmyard manure a typical, 446; manufacture of, 445; object of, 445; purposes served by, 445; substance used for, 447.
- Compound bones, 372.
- Concretionary nodules, composition of, 328.
- Conglomerate, 341.
- Connecticut, experimental station at, 33.
- Cooke, F. J., on, farmyard manure 272, 277; field experiments, 547—manuring of barley, 497—of manure, 514—of meadow-land, 509—of swedes, 514—of wheat, 501.
- Copper, oxide of, in plants, 55.
- Copperas, as a fixer, 246, 247.
- Coprolites, 373; percentage of phosphates in, 201; occurrence of, 201-373.
- Corcovado guano, nitrogen in, 329—phosphoric acid in, 329.
- Cordilleras, 340, 341.
- Costra, 341.
- Cotton-cake, decorticated, manurial constituents in, 282.
- Cotton-cake, undecorticated, manurial constituents in, 282.
- Cotton-seeds, imports of, 153.
- Cova, 341.
- Covered manure, potatoes grown with, 289; wheat grown with, 289.
- Cow-dung, alkalies in, 226; composition of, in dry state, 227; cooling, 225; nitrogen in, 226; phosphoric acid in, 226; water in, 226.
- Cow-manure, 247; amount voided per day, 248; amount voided per year, 248; analysis of, 286; dry matter in, 248; fermentation in, slow, 248; mineral matter in, 248; mucilaginous matter in, 248; nitrogen in, 248; resinous matter in, 248.
- Cow-urine, alkalies in, 230; composition of, in dry state, 231; fertilising ingredients in, for food consumed, 232; nitrogen in, 230; phosphoric acid in, 230; water in, 230.
- Cows, percentage of food voided in excrements of, 281; solid excrements of, 280; urine voided by, 280.

- Cress, experiments with, 41.
 Crimea, bones from, 360.
 Cropped soils, nitrates in, 157—lost by drainage in, 141.
 Crops, capacity of, for assimilating manures, 486; difference in root-systems of, 488; manuring of common farm, 493-530; period of growth of, 489; potash removed in, 218; suited for sewage, 434; variation in composition of, 490.
 Crusius on phosphoric acid removed from the farm, 207.
 Crust guanos, 308, 379.
 Crystalloids, 491.
 Curaçao phosphates, 308, 330, 379.
 Darmstadt experiments with basic slag, 410-413.
 Darwin on origin of nitrate-fields, 335.
 Daubeny on mineral sources of phosphoric acid, 200.
 Davy, Sir Humphry, lectures of, on agricultural chemistry, 17-19; on heat and water absorbing and retaining properties of soils, 57; on hygroscopic power of soils, 99.
 Dehérain, on nitrification, 52; on nitrification in sulphate of ammonia, 191; on rate of nitrification, 186.
 Denitrification, 177; conditions favourable for, 178; effected by bacteria, 178.
 Derby, Lord, introduction of Peruvian guano by, 301.
 Detmer on humus in soil, 47.
 Dew, action of, on guano, 300; explanation of, 77; most abundant in summer, 78.
 Dicalcic phosphate, 387; formula of, 398; molecular composition of, 398; percentage composition of, 398.
 Digby, Sir Kenelm, on value of nitrates to plants, 45; theory of, on plant-food, 6-8.
 Diorite, phosphoric acid in, 202, 211.
 Direct manures, 113.
 Dissolved-bone compound, 372.
 Dissolved bones, 368; composition of, 371.
 Dissolved guano, 310.
 Dolerite, phosphoric acid in, 202, 211.
 Dolomite, phosphoric acid in, 202, 211.
 Downton experiments on sewage-sludge, 439.
 Drainage, average of thirteen years, 160; nitrates in, 160; nitrates lost by, 140; phosphoric acid lost by, 206; potash lost by, 217.
 Drainings of manure-heaps, analysis of, 290.
 Dried blood, 424; composition of, 424; manure for sugar-cane, 425; potash in, 219; rate of nitrification in, 192; source of nitrogen, 152; suited for horticulture, 425.
 Dried flesh, 425; nitrogen in, 425.
 Dried leaves, as litter, 242; composition of, 242; nitrogen in, 242; phosphoric acid in, 242; potash in, 242.
 Ducks' dung, analysis of, 331.
 Duhamel and Hales, theory of, on plant-growth, 8.
 Dundonald, Earl, treatise by, on agricultural chemistry, 13.
 Dung and urine, composition of, 234.
 Dutrochet on absorption of plant-food, 55.
 Dyer, Dr Bernard, analyses of stable manure by, 283; experiments on peat as litter, 240; on nitrate of soda as manure for mangolds, 349.
 Earth, an adulterant of guano, 319; composition of solid crust of, 102.
 Ecuador, guano deposits at, 327.
 Egyptian guano, nitrogen in, 329; phosphoric acid in, 329.
 Elbe, waters of, phosphoric acid in, 206; potash in, 217.
 Elm-tree, water transpired by, 71.
 Enderbury Island guano, 309, 328; phosphoric acid in, 328.
 Endosmosis, 55.
 English farming, 86.
 Equalised guano, 311.
 Essex, coprolites from, 374.
 Estremadura phosphate, 375.
 Ethylamine, nitrification in, 182.
 Evaporation from soil, 71, 72, 98.
 Excreta, amount of nitrogen in, 149, 292; composition of, 226, 292; difference in amount of, for food con-

- sumed, 279; liquid, in farmyard manure, 224; solid, in farmyard manure, 224; solid, undigested food in, 224; solid, voided by cows, 280, 292; solid, voided by horse, 292; solid, voided by oxen, 280; solid, voided by sheep, 280, 292.
- Factors for calculating manurial ingredients into their different compounds, 553.
- Falkland guano, 308; nitrogen in, 330; phosphoric acid in, 330.
- Fallow-fields, nitrates formed in, 188.
- Fanning Island guano, 328; phosphoric acid in, 330.
- Farmyard manure, 223-292; action of, on soils, 273; ammonia in, 258; amount produced on farm per year, 252; analyses of, 259, 286; application of, 264; ash of, 287, 288; carbonic acid gas in, 258; classes of constituents of, 224; compared with artificials, 476; composition of, 259; denitrification in, 179; depth to plough to, 267; effect of, on potatoes, 520; fertilising matter in, 270; fire-fang in, 264; fresh, composition of, 286, 288; functions of, 268; heat in fermentation of, 78, 253; humates in, 259; humic acid in, 258; inadequate source of nitrogen to soil, 271; indirect influence of, 273; influence of, on soil, 475; Lawes, Sir John, on composition of, 291; Lord Kinnaid's experiments with, 289; marsh-gas in, 258; mineral matter in, 260; moisture in, 260; nitric acid in, 259; nitrogen in, 260; ratio of, to ash ingredients, 271; organic matter in, 260; phosphor-etted hydrogen in, 258; phosphoric acid in, 260; potash in, 260; products of decomposition of, 257; rate of application of, 275; retrogression of nitrogen in, 142; rotten, composition of, 287, 288—value of, 261; rotting, effects of, on, 262; solid excreta in, 224; sulphuretted hydrogen in, 258; supplemented with nitrogen, 271; supplemented with phosphoric acid, 272; temperature, effect of, on soil, 79, 274; typical compost, 446; ulmates in, 259; ulmic acid in, 258; unfavourable to certain crops, 477; urine in, 228; value of, 268; variation in composition of, 223; water in, 258.
- Fatty acids in guano, 305.
- Felspars, 103; albite, 103; composition of, 103; labradorite, 220; oligoclase, 103, 214, 220; orthoclase, 103, 214, 220; phosphoric acid in, 211; potash manures, 213; potash in, percentage of, 213, 220.
- Ferment, aerobic, 173, 255; anaerobic, 255.
- Fermentation, ammonium carbonate formed during, 245; in bones, 365; heat of, 79; of farmyard manure, 253; of guano, 299; temperature of, 256.
- Fern, bracken, as litter, 241.
- Ferric chloride, test for sulphocyanates, 355.
- Fertilisers and Feeding Stuffs Act, 543.
- Fertilising ingredients, amount of soluble, in soil, 90; amounts removed by different crops, 484, 485; chemical condition of, in soil, 89; lodge in seed, 491; in soil, 87.
- Fertility, of the soil, 65-97; potential, of soil, 214, 549; properties necessary for, 66; supply of oxygen necessary for, 81.
- Field experiments, 545, 548; educational value of, 547; on rate of nitrification, 187.
- Finger-and-toe prevented by lime, 461.
- Fire-fang in farmyard manure, 264.
- Fischer on absorption of plant-food, 55.
- Fish-guano, 320-323; application of, 323; consumption of, 152; manufacture of, 321; nitrogen in, 321; phosphoric acid in, 321; production of, 322; source of nitrogen, 152; value of, 322.
- Fixers, 246; chemical reactions with, 284.
- Fleece, potash in, 217.
- Fleischer, Professor, on solubility of phosphates, 408.
- Flesh-guano, 320.
- Flint Island guano, 309.

- Flitcham experiments on growth of wheat, 500.
 Floated bones, 362, 365.
 Florida phosphate, 378.
 Fluorapatite, composition of, 210.
 Food, consumed by pigs, 281; dry matter of, voided in dung, 228; percentage of, in excrements, 281.
 Food-constituents, plant, necessary for nitrification, 170.
 Forbes, David, on nitrate-fields of Chili, 334.
 Forest-soils, absence of nitrification in, 193.
 Fowl-dung, 320, 326; analysis of, 331.
 Fownes on phosphoric acid in rocks, 202.
 Frankland, P. F., experiments on nitrification, 52, 167, 198.
 Franklin, Benjamin, experiment of, with gypsum, 462.
 Frey Bentos, meat-meal guano from, 324.
 Galapagos Islands, guano deposits at, 327.
 Garden earth, absorptive power of, 98; ammonia in, 128.
 Gas-liquor, ammonia in, 353.
 Gas-works, ammonia from, 353, 358.
 Gases, absorbed by soils, 81; present in soil, 100.
 Gazzeri on retention by soil of plant-food, 57.
 Geese-dung, analysis of, 331.
 Geic acid in humus, 47.
 Gelatin, nitrification in, 182; from bones, 364.
 Germany, agricultural research in, 32; bones imported from, 360; manufacture of meat-meal guano in, 324.
 Germination, influence of temperature on, 76; oxygen necessary for, 81.
 Gilbert, Sir J. Henry, on barley-manuring, 496; on Liebig's mineral theory, 28; on manuring of potatoes, 520; Presidential address of, 61; and see Lawes and Gilbert.
 Glauber on artificial production of nitre, 164.
 Glue, 364.
 Glycin, assimilated by plants, 47.
 Glycocoll, experiments with, 46.
 Gneiss, 106; phosphoric acid in, 207.
 Grandeau, Professor, on forms of plant-food in soil, 107; on loss of phosphoric acid, 207.
 Granite, 105; in guano, 303; phosphoric acid in, 202, 211; potash in, 214.
 Grass, Bangor experiments on, 508; effect of manure on, 505; influence of farmyard manure on, 506; manuring of, 504-510.
 Gray, Asa, on transpiration by plants, 71.
 Great Cayman guano, 379.
 Green manures, 113.
 Grouven on guano, 313.
 Guanape Island guano, 302, 327; nitrogen in, 329; phosphoric acid in, 329.
 Guanine, 304; experiments with, 46.
 Guano, 293-331; action of, as a manure, 312; adulteration of, 318; application of, 315; bat, 325; composition of, 305, 329; crust, 308; deposits of the world, 327; dissolved, 310; equalised, 309; fermentation of, 299; fertilising constituents in, 314; fish, 320-323; importance of, in agriculture, 293; inequality in composition of, 309; influence of, on farming, 294; meat-meal, 324; mode of application of, 315; nitrification in, rate of, 192; nitrogenous, 300-308; origin of, 297; Peruvian, 300-306; phosphatic, 308; quantity to apply, 317; rectified, 311; so-called, 320; source of phosphoric acid, 202; source of potash, 219; value of, as a manure, 296; variation in composition of, 299.
 Gulf of Mexico, guano deposits at, 328.
 Gulls, guano from, 297.
 Gunning on sources of plant-nitrogen, 42.
 Gunpowder, exports of, 149; nitrogen lost in, 149; production, annual, of, 149; saltpetre in, 149, 333.
 Gypsum, 462-464; absorptive power of, 98; action of, mode of, 462—on nitrification, 173; an adulterant of guano, 319; as a fixer, 246, 247,

- 285 ; decomposes double silicates, 463 ; favourable to clover, 464 ; as an oxidising agent, 464.
- Hales, Stephen, theory of, on plant-growth, 8.
- Hampe, Dr, on nitrogen in plants, 46.
- Harting on sources of plant-nitrogen, 42.
- Heat, of soils, 76-78 ; of fermentation, 78.
- Heiden, Dr, on application of farm-yard manure, 265 ; on fixation of bases and acids by soil, 59 ; on loss of ammonia from dung, 249 ; on percentage of food voided by animals, 253 ; on straw as litter, 244, 249.
- Hellriegel, on amount of water in soils, 75 ; on barley, 498 ; on nitrogen in plants, 44.
- Helmont, Van, theory of, on source of plant-food, 4.
- Henslow, Professor, on coprolites, 374.
- Heraus on organisms in soil, 95.
- Herbage, effect of manure on, 505.
- Herrings as manure, 321.
- Hervé-Mangon, experiments on action of light on plants by, 38.
- Hilgenstock on tetracalcic phosphate, 405.
- Hippuric acid, experiments with, 46 ; in farmyard manure, 257.
- Hire, De la, on evolution of gases by plants, 11.
- Hofmeister on horse excrements, 243.
- Hoof-guano, source of nitrogen, 152.
- Hoofs and horns, manure from, 425.
- Hops, manuring of, 528 ; potash removed by, 217 ; slow-acting manures benefit, 528.
- Horn, capable of nitrification, 182 ; as manure, 425 ; nitrogen in, 426 ; phosphoric acid in, 426.
- Hornblende, 105.
- Horse-dung, alkalies in, 226 ; composition of, in dry state, 227 ; hot, 225 ; nitrogen in, 225, 226 ; phosphoric acid in, 226 ; water in, 225, 226.
- Horse-manure, 242 ; amount produced per day, 243 ; amount produced per year, 243 ; analyses of, 283 ; dry matter in, 243 ; dry nature of, 245 ; fermentation rapid in, 245 ; mineral matter in, 243 ; nitrogen in, 243, 244.
- Horse-urine, alkalies in, 230 ; composition of, in dry state, 231 ; fertilising ingredients in, 232 ; nitrogen in, 230 ; phosphoric acid in, 230 ; water in, 230.
- Hosäus on assimilation of ammonia, 50.
- Howland Island guano, 309, 328 ; phosphoric acid in, 330.
- Huanillos, guano from, 302, 327 ; nitrogen in, 330 ; phosphoric acid in, 330.
- Huano, 297.
- Hueppe on organisms in soil, 95.
- Hughes, John, on bracken-fern as litter, 241 ; on composition of bracken, 283.
- Humates in farmyard manure, 259.
- Humboldt, A., discovery of Peruvian guano by, 300.
- Humic acid in farmyard manure, 258 ; in humus, 47.
- Humin in humus, 47.
- Humus, absorptive power of, 68, 98 ; evaporation from, 99 ; nature of, in soil, 47 ; soils improved by addition of, 273.
- Huon Island guano, 309, 328 ; phosphoric acid in, 330.
- Huxtable and Thompson on retention of plant-food by soil, 57.
- Hydrated silicates, 107, 459.
- Hydrochloric acid as a fixer, 245.
- Hydrogen, amount of, in plants, 40 ; source of, in plants, 40.
- Hygroscopic power of soils, 75.
- Ichaboe guano, 307 ; nitrogen in, 329 ; phosphoric acid in, 329.
- Independence Bay guano, 302, 327 ; nitrogen in, 329 ; phosphoric acid in, 329.
- India, nitre soils of, 162.
- Indirect manures, 113, 114, 449-473.
- Ingenhousz, John, experiments by, on nitrogen in plants, 41 ; on oxygen evolved by plants, 12.
- Insoluble phosphate, 386 ; value of, 396.
- Iodine, in ash of plants, 55 ; in nitrate of soda, 340, 342.

- Iquique, nitrate of soda from, 333.
- Iron in ash of plants, 54; necessary for plant-growth, 55; reversion in superphosphates caused by, 390, 399.
- Iron-works, ammonia from, 353, 355, 358.
- Irrigation, 431-433; intermittent, 434; subsoil, 432.
- Jamieson, Professor, experiments with coprolites, 380.
- Jarvis Island guano, 309, 328; phosphoric acid in, 330.
- Jersey, manuring of potatoes in, 521.
- Johnson, Professor S. W., on application of superphosphate, 395; on Earl Dundonald, 13; on nitrogen in buffalo-horn shavings, 426; on nitrogen in soils, 123; on solubility of basic slag, 408; value of organic nitrogen to plant, 46.
- Jürgensen on nitrogen in excreta, 234.
- Kainit, as a fixer, 247; potash in, percentage of, 214, 220, 421; rate of application of, 423.
- Kaolin clay, analysis of, 104.
- Karmrodt, analysis of Chincha Island guano, 305; of concretionary nodules, 328.
- Karnallite, potash in, 220.
- Kellner, experiments on nitrification by, 52.
- Kelp, potash in, 420.
- Kieserite, 420.
- Kinnaird, Lord, experiments by, with farmyard manure, 289.
- Kitchen-garden soil, nitrogenous matter in, 122.
- Knop on condition of nitrates in soil, 138.
- Koosaw River, phosphates from, 376.
- Kreatin assimilated by plants, 47.
- Kuria Muria guano, 309, 328.
- Labrador, guano deposits at, 328.
- Labradorite, 214; potash in, 220.
- Lacpede Island guano, 309, 328; phosphoric acid in, 330.
- Lahn phosphate, 379.
- Lava, phosphoric acid in, 202, 211.
- Lawes, Sir J. B., and Gilbert, early researches of, at Rothamsted, 34; experiments with farmyard manure, 271; experiments with Peruvian guano, 301; inauguration of Rothamsted experiments by, 33; on composition of farmyard manure, 291; on manuring of wheat, 483; on motion of plant's sap, 56; on percentage of food in excreta, 233; on rate of nitrification, 186; on sources of plant-nitrogen, 43; on sulphate of ammonia, 356; on unexhausted manures, 550, 557-559.
- Lawes, Sir J. B., experiments with guano by, 301; manufacture of superphosphate by, 382; on application of superphosphate, 395; on bones, 359; on composition of farmyard manure, 291; on farmyard manure, 477; on loss of nitrates, 142; on sources of nitrogen, 154.
- Leather, as manure, 428; nitrogen in, 428.
- Leaves, dried, as litter, 242; nitrogen in, 242; phosphoric acid in, 242; potash in, 242.
- Legrange, Charles, on extent of nitrate-fields, 343.
- Leguminous plants, benefited by basic slag, 414—by potash, 523; fixation of free nitrogen by, 42; gain of nitrogen with, 135; manuring of, 522-527, 530; nitrogenous manures hurtful to, 523.
- Lehmann on ammonia as plant-food, 50, 352.
- Leipzig, bones from, 361.
- Leones, guano deposits at, 327.
- Leucite, potash in, 220.
- Lias chalk, phosphoric acid in, 211.
- Liebig, criticism of humus theory by, 25; dissolved bones discovered by, 361; first report to British Association, 24; manufacture of superphosphate from bones by, 359; mineral theory of, 26-29; on ammonia as a manure, 352; on importation of bones by Britain, 360; researches of, in agricultural chemistry, 23-32; services of, to agricultural chemistry, 31; theory of manures by, 29; theory of, on rotation of crops, 29.
- Light, action of, on plant-growth, 38.

- Lime, 449-461; abundant occurrence of, 452; action of, 461—contradictory, 450—not thoroughly understood, 449—on nitrogenous organic matter, 460—on soil's texture, 455; antiquity of, as a manure, 449; binding effect of, 457; biological action of, 459; caustic, 453; chemical action of, 457; decomposes minerals, 458; different forms of, 453; effect of, on soils, 112; fixed by soils, 58; in ash of plants, 54; mechanical functions of, 455; mild, 453; necessary for nitrification, 171, 459—for plant-growth, 55, 450; neutralises acidity in soils, 458; phosphates of, 385-388; pig excrements contain, 281; prevents clay puddling, 456; returned to soil, 452; soils contain, 450-452.
- Limestone, analyses of, 106; evaporation of water from, 99; occurrence of, 452.
- Linseed, imports of, 153; manurial constituents of, 282.
- Linseed-cake, manurial constituents of, 282.
- Liquid manure, 442-444.
- Lithia in ash of plants, 55.
- Litter, loam as, 239; peat as, 240; straw as, 236; uses of, 236.
- Lloyd on fattening animals, 253.
- Loam, as litter, 239; evaporation of water from, 99; poor in fertilising matter, 239.
- Lobos, guano deposits at, 327.
- Lobos de Afuera guano, 302, 327.
- Macabi Island guano, 302, 327; nitrogen in, 329; phosphoric acid in, 329.
- Maercker, Professor, on destruction of nitrifying organisms, 177.
- Magnesia, fixed by soils, 58; in ash of plants, 54; in pig excrements, 281; necessary for nitrification, 171; necessary for plant-growth, 55; sulphate of, as a fixer, 246, 285.
- Maize, absorbs ammonia, 352; fertilising ingredients removed from soil by, 485; manurial constituents in, 282; source of nitrogen, 153.
- Malden Island guano, 309, 328; phosphoric acid in, 330.
- Malpighi on importance of atmospheric air for germination, 39.
- Malt-dust, manurial constituents in, 282.
- Manganese, oxide of, in ash of plants, 54.
- Mangels, fertilising ingredients removed from soil by, 485; guano a manure for, 318; manurial constituents in, 282; manuring of, 346, 511, 513, 514; Rothamsted experiments on growth of, 568.
- Manitoba soils, nitrogen in, at various depths, 156; rate of nitrification in, 186.
- Manure, cow, 247; farmyard, 223-292; horse, 243; liquid, 442-444; meaning of word, 109; pig, 250; sewage, 430-441; sheep, 251; stable, from peat-moss, 283—wheat-straw, 283.
- Manures, action of, 61; analysis of; interpretation of, 539-544; application of, 474-492; method of, 531-538; cash prices of, 555; equal distribution of, 531; functions of, 109; increase soil-fertility, 474; intrinsic value of, 545; lasting effects of, 483; methods of valuing, 544; minor artificial, 424-429; mixing of, 531-538; nitrogenous, 293-359; phosphatic, 359-417; potassic, 418-423; quantities of, applied to oats, 504; unexhausted, 549-552, 558; units for determining commercial value of, 554; valuation of, 539-559; value of, deduced from experiments, 548; various classes of, 111-114.
- Manurial constituents of various foods, 282.
- Manurial ingredients, unit value of, 544.
- Manuring of, barley, 495-498; beans, 525-527, 530; cabbages, 528; cereals, 493-504; clover, 524; common farm crops, 493-530; grass, 504-510; hops, 528; leguminous crops, 522-528; mangels, 511, 513, 514; oats, 493-504; peas, 527; potatoes, 517-522; roots, 510-517; turnips, 510, 511, 513-517; wheat, 499-501.

- Maracaibo guano, nitrogen in, 330 ; phosphoric acid in, 330.
- Marl, phosphoric acid in, 211.
- Marsh-gas from farmyard manure, 258.
- Meadow-hay, fertilising ingredients removed from soil by, 485 ; manurial constituents in, 282 ; Rothamsted experiments on manuring of, 570.
- Meadow-land, benefited by basic slag, 414, 508 ; manuring of, 508 ; Norfolk experiments on, 509.
- Meat-meal guano, 320, 324 ; composition of, 152 ; imports of, 324 ; manufacture of, 324 ; nitrogen in, 324 ; phosphoric acid in, 324 ; rate of nitrification in, 192 ; source of nitrogen, 152 ; value of, 324.
- Mechi on liquid manure, 442.
- Mejillones guano, 309, 327 ; phosphoric acid in, 330.
- Mène, on sources of plant-nitrogen, 42.
- Menhaddo, guano manufactured from, 322.
- Mexico phosphate, 308, 328.
- Mica, analysis of, 105 ; potash in, 214, 220.
- Micro-organisms, convert ammonia into nitrous acid, 167 ; convert nitrous acid into nitric acid, 168 ; effect fermentation, 80 ; effect fixation of free nitrogen, 44 ; effect nitrification, 161 ; oxidising power of, 197.
- Mild lime, 453.
- Milk, nitrification in albuminoids of, 182 ; nitrogen removed in, 147 ; phosphoric acid removed in, 207 ; potash removed in, 218.
- Mineral phosphates, 373-381 ; value of, as a manure, 380.
- Mineral salts necessary for nitrification, 52.
- Minor artificial manures, 424-429.
- Mixing manures, 532-538 ; ammonia lost in, 533 ; nitric acid lost in, 536 ; phosphates reverted in, 536.
- Moisture, atmospheric, action on guano, 300 ; in farmyard manure, 260 ; in manures, 543 ; necessary for nitrification, 52, 176.
- Molds, 94.
- Mona guano, 309.
- Mond, Ludwig, on nitrogen in coal, 354.
- Monks guano, 327 ; phosphoric acid in, 330.
- Monocalcic phosphate, 386 ; formula of, 398 ; molecular composition of, 398 ; percentage composition of, 398 ; reversion of, with iron and alumina compounds, 399 — with tricalcic phosphate, 399.
- Mulder on humus in soil, 47, 126.
- Müller, A., on nitrogen in soil, 121, 124.
- Munro, Dr J. M. H., on nitrification, 52 ; on sewage-sludge as manure, 439 ; on urine voided, 292.
- Muntz, on ammonia in air, 118 ; on nitrifying organisms in soil, 180 ; on oxidising power of micro-organisms, 197.
- Muriate of potash, application of, 423 ; forms calcium chloride, 422 ; harmful effects of, 421 ; more concentrated than sulphate, 422.
- Mustard, 139.
- Navassa phosphate, 308, 328, 379.
- Nesbit on composition of guano, 301.
- New Granada, guano deposits at, 327.
- New Zealand, meat-meal guano from, 324.
- Nile, nitrates in waters of, 159.
- "Nitraries," 163.
- Nitrate-fields, appearance of, 340 ; origin of, 334.
- Nitrate of soda, 332-351 ; amount exported from Chili, 151, 332, 351 ; amount imported into Britain, 151, 351 ; appearance of fields of, 340 ; application of, 347 ; Chili and Peru chief source of, 161 ; composition of, 343 ; crops suited by, 346 ; discovery of deposits of, 333 ; extent of deposits of, 342 ; encourages deep roots, 344 ; formation of fields of, 334-340 ; method of applying, 347 ; method of mining, 341 ; nitric acid in, source of, 337 ; nitrogen in, percentage of, 343 ; not an exhausting manure, 345 ; origin of fields of, 334 ; properties of, 343 ; quantity to apply, 348 ; shipments of, 351 ; soils benefited by, 348 ; source of

- nitrogen, 150; top-dressing with, 344.
- Nitrates, amount lost by drainage, 140; amount produced at different times, 189; amount in soil, 129; conditions diminishing loss of, 139; constantly formed in soil, 138; in barley-soils, 158; in cropped soils, 130, 157; in drainage-waters, 160, 188; in fallow-soils, 129; in manured wheat-soils, 131, 157; in soil, 129, 162; lost by drainage, 137; most formed in summer, 139; nitrogen as, in Rothamsted soils, 198; position of, in soil, 188; quantity formed in fallow-fields, 188.
- Nitre, beds, 163; occurrence of, 162; soils of India, 162.
- Nitric acid, amount of, supplied to soil by rain, 155; derived from seaweed, 337; formed from ammonia, 118; formed from nitrous acid, 168; in farmyard manure, 259; in soil, 128; lost in mixing manures, 536; most important nitrogen compound for plants, 161; relation of, to plants, 50; source of, in nitrate of soda, 337.
- Nitrification, 51, 52, 161-198; action of gypsum on, 173; alkalinity necessary for, 172; in asparagin, 182; bearing of, on agriculture, 193; in bones, 182; cause of, 165; conditions favourable for, 170; denitrification, 177-179; effected by micro-organisms, 51, 167; in ethylamine, 182; in fallow-fields, 184; food-constituents necessary for, 170; field experiments on rate of, 187; in gelatin, 182; in horn, 182; laboratory experiments on rate of, 185; in manures, 190, 192; in milk albuminoids, 182; mineral salts necessary for, 52; moisture necessary for, 52, 176; old theories on, 196; organic matter not necessary for, 169, 196; oxygen necessary for, 52, 173; plant-roots promote, 181; in rape-cake, 182; rate of, 183; rotation of crops, bearing of, on, 195; soil best suited for, 192; in subsoils, conditions favourable for, 181; substances capable of, 181; in summer, 183; sunlight, effect of, on, 176; temperature necessary for, 52, 175; in thiocyanates, 182; in urea, 182; in wool, 182.
- Nitrifying organisms, depth found at in soil, 180; distribution of, in soil, 179; effect of poisons on, 176; organic matter not required by, 169.
- Nitrobaeter*, 167.
- Nitrogen, 115-160; absorbed by soil, 81, 131; accumulates in pastures, 134; in air, 116; as ammonia in soils, 127; amount of, in plants, 40; amount of, in soil, 123; artificial supply of, 150; in bat guano, 325; in bones, 363, 364; combined, in air, 118; combined, in rain, 119, 155; condition of, in manures, 540; converted into nitrates in soil, 51; in cow-dung, 226-228; in cow excrements, 278; in cow-urine, 230; difference between surface and subsoil, 126; different forms of, 45, 116; dissolved in rain, 131; in dried blood, 424; in farmyard manure, 260; in fish-guano, 321; fixation of free, 136; forms of, in plants, 491; free, relation of, to plant, 117; gain of, with leguminous crops, 135; in guanos, 329; in hoofs and horns, 426; in horse-dung, 226-228; in horse-manure, 243; in horse-urine, 230; importance of, in soil, 88; in lean flesh, 424; in leather, 428; least abundant of manurial ingredients in soil, 271; loss of, artificial sources of, 144; loss of, by crops, 144; loss of, on farm, 146; loss of, sources of, 137-150; loss of, total amount of, 142; lost in the arts, 148; lost in free condition, 141; lost in treating farmyard manure, 146; lost in milk, 147; lost by retrogression, 142; in Manitoba soils, 156; in meat-guano, 324; nature of, in soil, 124; as nitrates in soil, 128; as nitrates in cropped soils, 130, 157; as nitrates in Rothamsted soils, 198; as nitrates in wheat-soils, 157; in nitrate of soda, 343; nitric, in soil, 128; organic, absorbed by plants, 47; organic, in soil, 125; original

- source of, in soil, 133; in oxen excrements, 280; in pasture-lands, 158; peat-soils richest in, 123; in Peruvian guano, 302, 306, 307, 329; in pig-dung, 226-227; position of, in agriculture, 115-160; relative manurial value of, 556; Rothamsted experiments on, 115; in scutch, 427; in sewage, 431; in sewage-sludge, 439; in sheep-dung, 226-228; in sheep excrements, 280; in sheep-urine, 230; in soil, 120; in soil, portion of, easily nitrifiable, 187; in soils at various depths, 156; in soot, 428; source of, in plants, 15, 16, 40-52; sources of soil, 131-137; in straw, 237, 243; in subsoil, 121; in surface-soil, 121; in swine-urine, 230; in wool-len rags, 427.
- Nitrogenous guano, 300-308, 329.
- Nitrogenous manures, application of, 478; benefit cereals, 494; hurtful to leguminous crops, 523.
- Nitrogenous organic substances, in Chincha guano, 305; in concretionary nodules, 328.
- Nitrosomonas*, 167.
- Nitrous acid, converted into nitric acid, 168; formed from ammonia, 167.
- Nobbe, on fixation of free nitrogen, 136; on potash in soil, 108.
- Nöllner on origin of nitrate-fields, 339.
- Norfolk, coprolites from, 374; experiments on barley, 497—on meadow-land, 509—on turnips, 513.
- North America, guano from, 298, 328.
- Norwegian apatite, 375.
- Oak-tree, water transpired by, 71.
- Oat-straw, composition of, 238; manurial constituents in, 282.
- Oats, Arendt's experiments with, 503; avenine in, 503; fertilising ingredients removed from soil by, 485; hardy crop, 502; manurial constituents in, 282; manuring of, 501-504; nitrogen removed in crop of, 148; require mixed nitrogenous manures, 502; source of nitrogen, 153; Rothamsted experiments on growth of, 567.
- Oficinas*, 342.
- Ohlendorff, introduction of dissolved guano by, 311.
- Oilcakes, imports of, 153; source of nitrogen, 153.
- Oil-seeds, source of nitrogen, 153.
- Oligoclase felspars, 103, 214; composition of, 103; potash in, 220.
- Organic matter, in bones, 363; in dung, 228, 260; in manures, 543; not necessary for nitrifying organism, 169.
- Orthoclase felspars, 103, 214; composition of, 103; potash in, 220.
- Ox-dung, fertilising ingredients in, for food consumed, 228.
- Ox-urine, fertilising ingredients in, 232.
- Oxalic acid in guano, action of, 330.
- Oxen, excrements of, 280; food aided by, 280; solid excreta voided by, 280; urine voided by, 280.
- Oxidation, 79; products of, 79, 80.
- Oxygen, absorbed by plant-roots, 81; absorbed by soil, 81; evolved by plants, 11; necessary for fertility, 81; necessary for nitrification, 52, 173; percentage of, in plants, 39; source of, in plants, 39.
- Pabellon de Pica, guano from, 298, 302, 327; nitrogen in, 330; phosphoric acid in, 330.
- Pacific Islands, guano from, 298.
- Pacific Ocean, sea-weed in, 339.
- Palagonite as potash manure, 213.
- Palm-kernel meal, manurial constituents in, 282.
- Pasteur, on fermentation in urine, 255; on nitrification, 166.
- Pastures, accumulation of nitrogen in, 134; benefited by basic slag, 414; deficient in lime, 451; effect of manure on herbage of, 505; nitrogen in, 158; permanent, 138, 194—manuring of, 509; season influences, 507; soil influences, 507.
- Patagonian guano, 308, 327; nitrogen in, 330; phosphoric acid in, 330.
- Patent phosphate meal, 405.
- Patillos, guano deposits at, 327.
- Patos Island, guano deposits at, 328; phosphoric acid in, 330.
- Patterson on superphosphate, 399.

- Payen and Boussingault on composition of dried flesh, 425.
- Peas, manurial constituents in, 282; manuring of, 527; phosphorus in, 205; source of nitrogen, 153.
- Peat, absorbing properties of, 239; adulterant of guano, 317; analysis of stable-manure from, 281; litter, 239; nitrogen in, 240; retaining properties of, 240; soils, 123.
- Pelicans, guano from, 297.
- Penguin Island guano, 330; nitrogen in, 330; phosphoric acid in, 330.
- Penguins, guano from, 297.
- Percival on carbonic acid in plants, 12.
- Peru, guano deposits in, 327; guano first used in, 297; nitrate of soda from, 161, 162.
- Peruvian guano, 300-306; appearance of, 303; composition of, 304-306; deposits of, 301; imports of, 151, 297; source of nitrogen, 151.
- Peters and Eichhorn on solvent power of salt, 471.
- Petzholdt on sources of plant's nitrogen, 42.
- Pfeffer on action of light on plant-growth, 38.
- Phoenix Island guano, 309.
- Phosphate of iron in Chincha guano, 305.
- Phosphate of lime, in Algerian phosphate, 379; in apatite, 374; in Belgian phosphate, 377; in bones, 364; in Cambridge coprolites, 374; in Carolina phosphates, 376; in crust guanos, 379; in Estremadura phosphate, 375; in Florida phosphate, 378; in French phosphates, 379; in Lahn phosphates, 379; in Somme phosphate, 378; reverted in mixing manures, 537.
- Phosphates of lime, 385-388, 398; importance of mechanical condition of, 542.
- Phosphates, mineral, 373-381; imports of, 381; value as a manure, 380.
- Phosphatic guano, 308, 330.
- Phosphatic manures, application of, 480.
- Phosphoretted hydrogen in farmyard manure, 258.
- Phosphoric acid, 199-211; in ash of plants, 54; in basic slag, 404; in bat guano, 325; in bones, 363; condition of, in soil, 203; in cow-dung, 226-228; in cow excrements, 280; in cow-urine, 230; in farmyard manure, 260; in fish guano, 321; fixed by soils, 58; gain of, 208; in guano, percentage of, 329, 330; guano a source of, 202; in hoofs and horns, 426; in horse-dung, 226-228; in horse-urine, 230; importance of, 88; loss of, artificial sources of, 206—by drainage, 206—in farmyard manure, 208—in milk, 207—in sewage, 208—sources of, in agriculture, 205; in meat-guano, 324; mineral sources of, 200; necessary for plant-growth, 55; occurrence of, in animals, 205—in nature, 199—in plants, 204—in soil, 203; in oxen excrements, 280; in pig-dung, 226, 227; in pig excrements, 281; in pig-urine, 230; position of, in agriculture, 199-211; relative trade values of, in manures, 400; in rocks, 202, 211; in sewage-sludge, 441; in sheep-dung, 226-228; in sheep excrements, 280; in sheep-urine, 230; statement of, in analyses of manures, 541.
- Phosphorite, 201, 374.
- Phosphorus, in albuminoids, 205; in animals, 205; in beans, 205; in peas, 205; in plants, 204; in pig-iron, 401.
- Physical properties of soils, 66-87.
- Pichard on action of gypsum on nitrification, 173.
- Pig-dung, composition of, 226; in dry state, 227.
- Pig excrements, 281; composition of, 281.
- Pig-manure, 250; amount produced per day, 251; mineral matter in, 251; nitrogen in, 251; poor in nitrogen, 251.
- Pig-urine, composition of, 230—in dry state, 231.
- Pigeon-dung, 320, 325; analysis of, 331.
- Pigs, excrements of, 281; food consumed by, 281.
- Pisagua, nitrate-fields at, 340.
- Plant, action of light on, 38; amount

- of hydrogen in, 40—nitrogen in, 40—oxygen in, 40; ash constituents of, 53-55; carbon fixed by, 37, 38; food, absorption of, by, 55; phosphoric acid in, 204; potash in, 216; proximate composition of, 36; relation of ammonia to, 48-50; source of hydrogen in, 40—nitrogen in, 40-52—oxygen in, 39, 40.
- Plant-food, absorption of, 490; amount of soluble, in soil, 100; early theories on source of, 4; retained by soil, 57.
- Plant-roots, grow downwards, 84; nitrification promoted by, 181; openness required by, 83; room required by, 85; soil in relation to, 84.
- Pliny, on lime as a manure, 449; on salt as a manure, 465.
- Pockets a source of phosphoric acid, 202.
- Poisons, effect of, on nitrifying organisms, 176.
- Polstorff on ash constituents of plants, 53.
- Polyhallite, potash in, 220, 420.
- Porphry, in guano, 303; phosphoric acid in, 202, 211.
- Potash, 212-220, 418-423; in ash of plants, 54; in barilla, 420; chloride of, 218; condition of, in soil, 216; in cows' excrements, 280; in drainage-waters, 217; in farmyard manure, 260; in felspars, 220; in fleece, 217; fixed by soils, 58; importance of, in soil, 88; in kelp, 420; less important than phosphoric acid, 212; manures, 218, 418-423; muriate of, 218, 421; necessary for nitrification, 171; necessary for plant-growth, 55; occurrence of, 213; in ocean, 213; in oxen excrements, 280; in pig excrements, 280; in plants, 216; position of, in agriculture, 212-220; relative manurial value of, 556; Scottish soils supplied with, 419; in sheep excrements, 280; soda replaces, 466; sources of loss of, 217; in Stassfurt salts, 214; statement of, in analyses of manures, 542; in sugar-beet refuse, 219; sulphate of, 218, 421; in wood-ashes, 218, 220, 419.
- Potash manures, 218, 418-423; application of, 422, 480—rate of, 423; barilla as, 420; crops suited for, 423; relative importance of, 418; soils suited for, 423; sources of, 419; Stassfurt salts as, 420; wood-ashes a source of, 419.
- Potassium phosphate in concretionary nodules, 328.
- Potassium sulphate, in Chincha guano, 305; in concretionary nodules, 328.
- Potatoes, effect of farmyard manure on, 520; fertilising ingredients removed from soil by, 485; grown with covered manure, 289; Highland Society's experiments on, 518; manurial constituents in, 282; manuring of, 517-522—in Jersey, 529—influences composition of, 521; potash removed in, 217; Rothamsted experiments on, 519, 571.
- Precipitated ammonium phosphate in concretionary nodules, 328.
- Precipitated phosphate, 330, 387.
- Precipitation, treatment of sewage by, 436.
- Priestley, discovery of evolution of oxygen by plants, 11; on nitrogen in plants, 40.
- Prussiate of potash, manufacture of, 353.
- Pugh on sources of plant-nitrogen, 42.
- Punta de Lobos guano, 302; nitrogen in, 303; phosphoric acid in, 303.
- Punta de Patillos, guano deposits at, 327.
- Pyroxene, potash in, 220.
- Quartz, evaporation of water from, 99.
- Queensland, meat-meal guano from, 324.
- Quercitan, experiments of, with roses, 8.
- Rape-cake, capable of nitrification, 182; manurial constituents in, 282.
- Rape-seeds, imports of, 153.
- Raza Island guano, 328; phosphoric acid, 330.
- Rectified guano, 311.
- Relative trade values of phosphoric acid, 400.

- Resin in guano, 305.
 Retentive power of soils for water, 70-73.
 Retrogression, nitrogen lost by, 142.
 Reverted phosphates, 389-391; determination of amount of, 391; formation of, 387; value of, 391.
 Rhine, nitrates in waters of, 158.
 Rice-meal, an adulterant of guano, 319; manurial constituents of, 282.
 Rocks, phosphoric acid in, 202.
 Roots, influence of manures on composition of, 512; manuring of, 510-522; Norfolk experiments on, 513; potash removed in, 217.
 Rotation of crops, bearing of, on nitrification, 195.
 Rotations, phosphoric acid in, 290; potash removed in, 290.
 Rothamsted, alternate wheat and bean rotation at, 524; ammonia in rain at, 49; barley experiments at, 566; Broadbalk Field, alteration in composition of, 159—manuring of, 159—produce of wheat on, 159; early experiments at, 33-36; experiments, 560-572; experiments with nitrate of soda at, 347; experiments on nitrogen question at, 115—mangel-wurzel, 568—oats, 567—potatoes at, 519—value of nitrogen in farmyard manure, 271; increase of nitrogen with manures at, 137, 513; nitrates in barley-soils of, 158; nitrates in cropped soils of, 130, 157; nitrates in drainage of, 189; nitrates in wheat-soils of, 131, 157; nitrogen as nitrates in soils of, 129, 198; nitrogen, decrease of, in soils, 159; nitrogen in pasture at, 126; pasture, increase of nitrogen in, 158; retrogression of nitrogen at, 142; soil, nature of, 561—nitrogen in, at various depths, 156; total amount of nitrogen lost at, 142; turnip experiments at, 568; unmanured fallow-land loses nitrogen by drainage at, 141; wheat experiments at, 500, 562-565.
 Roy on sources of plant-nitrogen, 42.
 Rubidia in ash of plants, 55.
 Ruffle, John, on superphosphate, 388.
 Rye, manurial constituents in, 282.
 Rye-grass suited for sewage, 435.
 Rye-straw, summer, composition of, 238; winter, composition of, 238.
 St Helena, experiments at, with Peruvian guano, 301.
 Saldanha Bay guano, 328; nitrogen in, 329; phosphoric acid in, 329.
 Salinas, 335.
 Salm-Horstmar, Prince, on water culture, 54.
 Salt, 465-473; action of, on crops, 472; adulterant of guano, 319; amount applied, 473; antiquity of use of, 465; an antiseptic, 468; application of, 472; clarifies water, 470; coagulates clay, 470; decomposes minerals, 470; a germicide, 468; indirect action of, 468; mechanical action of, 470; nature of action of, 465; not a necessary plant-food, 466; occurrence of, 467; prevents rapid fermentation, 471; quantity to apply, 473; solvent action of, 470; sources of, 468.
 Saltpetre, formation of, 164; occurrence of, 215; plantations, 163.
 Sand, absorptive power of, 68; an adulterant of guano, 319; calcareous, absorptive power of, 98; siliceous, absorptive power of, 98.
 Sandy soils deficient in lime, 451.
 Sandwich Islands, guano deposits at, 328.
 Saragossa Sea, sea-weed in, 339.
 Saussure, De, on absorption of gases by soil, 81; on nitrogen in plants, 41; researches on plant-food by, 15.
 Sawdust an adulterant of guano, 319.
 Scheibler, Professor, on basic slag, 404.
 Schloesing and Müntz, on nitrification, 51, 166; experiments on rate of nitrification by, 185; on denitrification, 179; on ferments effecting nitrification, 167; on fixation of free nitrogen, 42; on ammonia in air, 119, 132; on nitrogen absorbed by soil from air, 132; on temperature favourable for nitrification, 175.
 Schoenite, potash in, 220.
 Schübler, on absorptive power of soils, 98; on retentive power of soils, 98.

- Schulze on fixers, 246.
 Scutch, 427; manufacture of, 427; nitrogen in, 427.
 Sea-weed, nitric acid in, 339.
 Seals, guano from, 297.
 Seed, fertilising ingredients lodge in, 491.
 Seine, nitrates in waters of, 158.
 Sénébier, Jean, on carbon in plants, 12; on nitrogen in plants, 41.
 Sewage, 430-441; charcoal a filter for, 437; crops suited for, 434; denitrification in, 179; dry matter in, 431; effects of continued applications of, 433; filters for, 437; irrigation with, 431-433; nitrification in, 166; nitrogen lost in, 149; phosphoric acid lost in, 149; purified by soils, 435; treatment of, by precipitation, 436; value of, as a manure, 430.
 Sewage-sick land, 433.
 Sewage-sludge, 438-441; as a manure, experiments with, 438; nitrogen in, 439; phosphoric acid in, 439; profitable treatment of, 441; value of, 439; water in, 438.
 Shale-works, sulphate of ammonia, from, 358.
 Shark's Bay guano, 309, 328.
 Sheep, excrements of, 280, 281; solid excreta voided by, 280; urine voided by, 280.
 Sheep-dung, alkalies in, 226; composition of, in dry state, 227; most valuable excrement, 227; nitrogen in, 226; phosphoric acid in, 226; water in, 226.
 Sheep-manure, 251; amount produced per day, 251—per year, 252; dry matter in, 252; mineral matter in, 252; nitrogen in, 252.
 Sheep-urine, alkalies in, 230; composition of, in dry state, 231; most valuable urine, 231; nitrogen in, 230; phosphoric acid in, 230; water in, 230.
 Shoddy, 427; production of, 152, 425; nitrogen in, 152, 427.
 Sicily, bones from, 360.
 Sidney Island guano, phosphoric acid in, 330.
 Siemens, Dr, experiments by, with light on plants, 38.
 Silica, in ash of plants, 55; in Chincha guano, 305; jelly, 169; necessary for plant-growth, 55.
 Silicates, 102; absorbed by cereals, 494.
 Silicic acid fixed by soils, 58.
 Simon on humus in soil, 47.
 Slaked lime, 454.
 Slugs killed by lime, 461.
 Smut prevented by lime, 461.
 Soda, in ash of plants, 54; fixed by soils, 58; necessary for plant-growth, 55; nitrate of, 332-351; in *salinas*, 335; replaces potash, 466.
 Sodium chloride in Chincha Island guano, 305.
 Sodium phosphate in concretionary nodules, 328.
 Sodium sulphate in concretionary nodules, 328.
 Soil, 65-108; absorptive power of, for water, 67, 98; acids fixed by, 58-60; action of lime on, 453; ammonia absorbed by, 81; amount of soluble plant-food in, 100; artificial, 54; barley, nitrates in, 158; bases fixed by, 58-60; best suited for nitrification, 192; biological properties of, 92-96; capacity for heat, 76-78; carbonic acid absorbed by, 81; chemical composition of, 87-92, 101-107; colour of, 80; cropped, nitrates in, 157; denitrification in, 177; evaporation from, 71, 72; farmyard manure, action of, on, 272; fertilising ingredients in, 87; fertility of, 65-108; fineness of, 69-70; gases in, 100; hygroscopic power of, 75-76, 99; improved by humus, 272; influence of farmyard manure on, 475; on nitrification, 180; manures increase fertility of, 474; nitrates in, amount of, 128-131; nitrifying organisms in, 179; distribution of, 179; nitrogen absorbed by, 81, 82, 131; nitrogen accumulates, 133; nitrogen in, amount of, 120-128; nitrogen least abundant of manurial ingredients in, 270; nitrogen at various depths in, 156; oxygen absorbed by, 81; phosphoric acid in, 203—condition of, in, 203—occurrence of, in, 203;

- peat, 123 ; possesses power of fixing ammonia, 57 ; potash in, 215—condition of, in, 216 ; potential fertility of, 549 ; power of, for absorbing gases, 81 ; relation of, to plant-roots, 84 ; retention of plant-food by, 57 ; retentive power of, for water, 70-73 ; sewage purified by, 435 ; shrinkage of, 74 ; variation in absorbing powers of, 82 ; varieties of, 67 ; virgin, 133 ; water in, most favourable amount of, 75 ; water-logged, 179 ; wheat, nitrates in, 157.
- Soluble phosphate, 386.
- Sombrero phosphate, 308, 328, 330, 379 ; phosphoric acid in, 330.
- Somme phosphate, 378.
- Soot, 428 ; application of, rate of, 429 ; crops suited by, 429 ; nitrogen in, 428.
- South America, guano deposits in, 327 ; meat-meal guano from, 324.
- Starbuck Island guano, 309, 328 ; phosphoric acid in, 330.
- Stassfurt salts, 214 ; potash in, 215, 420.
- Stead and Ribsdale on formation of basic slag, 407.
- Stoeckhardt, on composition of solid excreta, 226 ; on composition of urine, 229.
- Storer, Professor, on composition of birds' dung, 331 ; on composition of leaves, 242 ; on fish-guano, 323 ; on nitrogen removed in milk, 147.
- Straw, composition of, 238 ; imports of, 153 ; as litter, 236, 248 ; mineral matter in, 238, 243 ; nitrogen in, 237, 243 ; variation in composition of, 237.
- Subsoil, conditions favourable for nitrification in, 181.
- Suffolk coprolites, 374.
- Sugar-beet refuse, potash in, 219.
- Sulphate of alumina, a precipitant of sewage, 437.
- Sulphate of ammonia, 352-358 ; ammonia in, 355 ; application of, 356 ; composition of, 355 ; a concentrated nitrogenous manure, 356 ; converted into nitrates, 356 ; from gas-works, 353 ; from iron-works, 355 ; from shale-works, 354 ; manure for cereals, 356 ; most easily nitrifiable manure, 191 ; production of, 151, 358 ; properties of, 355 ; source of nitrogen, 149 ; sources of, 353, 354, 358 ; sulphocyanate of ammonia in, 355.
- Sulphate of lime a fixer, 246.
- Sulphate of magnesia, an adulterant of guano, 319 ; as a fixer, 246.
- Sulphate of potash, application of, 422—rate of, 423 ; compared with muriate, 421 ; sources of, 218, 420.
- Sulphuretted hydrogen from farm-yard manure, 258.
- Sulphuric acid, action of, on bones, 382—on guano, 311—on tricalcium phosphate, 398 ; in ash of plants, 54 ; as a fixer, 245, 285 ; necessary for plant-growth, 55 ; superphosphate manufactured with, 384, 388.
- Superphosphate, 382-400 ; action of, 392-395—sometimes unfavourable, 395 ; application of, 395—rate of, 397 ; composition of, 391 ; discovery of, 382 ; hastens early growth, 394 ; high-class, 392 ; low-class, 392 ; manufacture of, 383-385—phosphates suitable for, 384 ; medium-class, 391 ; production of, 382 ; reversion in, 389, 399, 400—causes of, 389, 390 ; reverted in soil, 392.
- Surprise Island guano, 328.
- Swan Island guano, 328.
- Swedes, fertilising ingredients removed from soil by, 485 ; manurial constituents in, 282 ; manuring of, 514.
- Swine-dung, alkalies in, 226 ; composition of, 227 ; nitrogen in, 226 ; phosphoric acid in, 226 ; water in, 226.
- Swine-urine, alkalies in, 230 ; composition of, 231 ; nitrogen in, 230 ; phosphoric acid in, 230 ; water in, 230.
- Sydney Island guano, 309.
- Syenite, 106 ; phosphoric acid in, 202, 211.
- Sylvin, potash in, 220.
- Symbiosis*, 44.
- Tamarugal, Pampa de, nitrate deposits in, 340.
- Tarapaca, nitrate deposits in, 340.
- Temperature necessary for nitrification, 52, 175.

- Tetracalcic phosphate, 387; occurrence of, 387, 405; solubility of, 387.
- Thaer on application of farmyard manure, 275.
- Thiocyanates, nitrification in, 182.
- Thomas-Gilchrist process of steel-smelting, 402.
- Thomas-slag. See Basic slag.
- Tillage increases number of plants, 86.
- Timor Island guano, 309.
- Tobacco, potash in, 217.
- Torrefied horn, 426.
- Torrefied leather, 428.
- Tortola guano, 309.
- Trachyte, phosphoric acid in, 202, 211.
- Transpiration, by elm-tree, 71; by oak-tree, 71.
- Trees, as pumping-engines, 76; water transpired by, 71.
- Tricalcic phosphate, 386, 398.
- Tubercles on roots of plants, 44.
- Tull, Jethro, theory of, on plant-growth, 9-11, 69, 109.
- Turkey, dung produced by, 331.
- Turnips, fertilising ingredients removed from soil by, 485; manurial constituents in, 282; manuring of, 510, 511, 513-517; Rothamsted experiments on growth of, 568.
- Twigs, potash in, 217.
- Tyrosin, assimilated by plants, 47.
- Ulmates in farmyard manure, 259.
- Ulmic acid, in farmyard manure, 258; in humus, 47.
- Ulm in humus, 47.
- Uncovered farmyard manure, 263, 289.
- Unexhausted manures, valuation of, 549-552, 558.
- Unit value of manurial ingredients, 544.
- Units for determining commercial value of manures, 554.
- Urate of ammonium in Chinch Island guano, 305.
- Urea, assimilated by plants, 46; in farmyard manure, 257; nitrification in, 182.
- Uric acid, experiments with, 46; in Chinch Island guano, 305.
- Urine, 228; amount voided, 291; composition of, varies, 228; contains digested manurial ingredients, 228, 232; devoid of phosphoric acid, 205; and dung, composition of, 234; influence of food on, 229; nitrification in, 197; nitrogen in, 292; potash in, 292; voided by cows, 280; voided by oxen, 280; voided by pigs, 281; voided by sheep, 280.
- Uruguay, meat-meal guano from, 324.
- Valuation of manures, 539-559.
- Vegetation, desirable to have soil covered with, 194.
- Venezuela, guano deposits at, 327.
- Ville, Georges, on assimilation of ammonia, 50; theory of, on source of plant-nitrogen, 41.
- Vine, potash removed by, 216.
- Virgin soils, 133.
- Voelcker, Dr, analysis of apatite, 210—of farmyard manure, 259; on action of superphosphate, 395; on fresh and rotted dung, 261, 286; on guano, 316; on salt as a manure, 473.
- Voss, Hermann, on manures used, 152.
- Wagner, Professor, on, application of basic slag, 416; assimilation of organic nitrogen, 46; experiments with basic slag, 408-413; fineness of basic slag, 409; manures, 412; relative manurial value of nitrogen compounds, 556; solubility of basic slag, 408.
- Wallace, Dr, on sewage purification, 436.
- Walrus, guano from, 297.
- Warington, R., on ammonia in rain, 49; on appearance of nitrous organisms, 168; on conditions favourable for nitrification, 181; experiments on rate of nitrification, 186; on composition of farmyard manure, 260; on manufacture of superphosphate, 383; on manurial constituents of foods, 282; on nitrification in alkaline solutions, 197; on nitrogen in excrements, 233; on nitrogen in soil, 122; on potash in wool, 227; researches of, on nitrification, 35, 52, 166-168, 180, 186.

- Water, absorbed by plants, 73 ; amount of, transpired by plant-leaves, 56 ; an adulterant of guano, 319 ; a carrier of plant-food, 55 ; in cow-dung, 226—cow-urine, 230 ; from decomposition of farmyard manure, 257 ; in horse-dung, 226—horse - urine, 230 ; necessary for plant, 67 ; in pig-dung, 226—pig-urine, 230—sheep - dung, 226—sheep - urine, 230 ; transpired by elm-tree, 71—oak-tree, 71.
- Water-culture, 54.
- Water-logged soils, 179.
- Waterloo, bones from, 360.
- Way, Thomas, on retention of plant-food by soil, 57, 59 ; on sewage, 437.
- West Indies, guano from, 298.
- Whales, guano from, 322.
- Wheat, fertilising ingredients removed from soil by, 485 ; Flitcham experiments on, 500 ; manurial constituents in, 282 ; manuring of, 499-501 ; nitrogen removed in crop of, 145 ; requires nitrogenous manures, 499 ; Rothamsted experiments on, 500, 562-565 ; a source of nitrogen, 153.
- Wheat-soils, nitrates in, 157.
- Wheat-straw, analysis of stable manure made from, 283 ; composition of, 238 ; manurial constituents in, 282.
- White clover, growth of, promoted by lime, 451.
- Wiegmann on ash constituents of plants, 53.
- Wilfarth on nitrogen in plants, 44.
- Wilting, 73.
- Winogradsky, on nitrification, 52, 167, 169, 197 ; on organisms in soil, 94.
- Wolff on, analysis of manure-heap drainings, 290 ; composition of fresh and rotten dung, 288 ; assimilation of organic nitrogen by plants, 47 ; relative manurial value of manurial compounds, 556 ; urine, 232.
- Wood-ashes as potash manure, 218, 419.
- Woodhouse, researches of, on nitrogen in plants, 41.
- Wool, capable of nitrification, 182 ; potash in, 217.
- Wool-waste, 427 ; nitrogen in, 427.
- Woolney, on organisms in soils, 93, 95 ; on water in soils, 75.
- Wrightson, Professor, on application of basic slag, 414.
- Yeast, 94.
- Yorkshire, bones first used in, 359.
- Zeolites, potash in, 220.

LIST OF
Educational Works

Published by
William Blackwood & Sons

45 GEORGE STREET, EDINBURGH
AND
37 PATERNOSTER ROW, LONDON

English Language and Literature.

A History of English Literature. For Secondary Schools. By J. LOGIE ROBERTSON, M.A., First English Master, Edinburgh Ladies' College. With an Introduction by Professor MASSON, Edinburgh University. Crown 8vo, 3s.

English Verse for Junior Classes. By the SAME AUTHOR. In 2 Parts. Part I.—Chaucer to Coleridge. Part II.—Nineteenth Century Poets. Crown 8vo, 1s. 6d. *net*, each.

Passages for Paraphrasing. Fcap. 8vo, limp cloth, 6d.

Exercises in Analysis, Parsing, and Correction OF SENTENCES. Fcap. 8vo, cloth limp, 6d.

A Manual of English Prose Literature, Biographical and Critical. By WILLIAM MINTO, M.A., Prof. of Logic and English Literature in the University of Aberdeen. Third Edition. Crown 8vo, 7s. 6d.

Characteristics of English Poets, from Chaucer TO SHIRLEY. By the SAME. Second Edition. Crown 8vo, 7s. 6d.

The Literature of the Georgian Era. By the SAME AUTHOR. Edited, with a Biographical Introduction, by Professor KNIGHT, St Andrews. Post 8vo, 6s.

Plain Principles of Prose Composition. By the SAME. Crown 8vo, 1s. 6d.

English Prose Composition: a Practical Manual for Use in Schools. By JAMES CURRIE, LL.D. Fifty-seventh Thousand. 1s. 6d.

Elementary Grammar and Composition. Based on the ANALYSIS OF SENTENCES. With a Chapter on WORD-BUILDING and DERIVATION, and containing numerous Exercises. New Edition. Fcap. 8vo, 1s.

A Working Handbook of the Analysis of SENTENCES. With NOTES ON PARSING, PARAPHRASING, FIGURES OF SPEECH, AND PROSODY. New Edition, Revised. Crown 8vo, 1s. 6d.

Latin and Greek.

Aditus Faciliores: an Easy Latin Construing Book, with Complete Vocabulary. By the late A. W. POTTS, M.A., LL.D., and the Rev. C. DARNELL, M.A. Tenth Edition. Fcap. 8vo, 3s. 6d.

Aditus Faciliores Graeci: an Easy Greek Construing Book, with Complete Vocabulary. By the SAME AUTHORS. Fifth Edition. Fcap. 8vo, 3s.

A Parallel Syntax. Greek and Latin for Beginners, with Exercises and a Greek Vocabulary. By the Rev. HERBERT W. SNEYD-KYNNERSLEY, LL.M., Trin. Coll., Cambridge; Head-Master of Sunninghill House, Ascot; Author of 'Greek Verbs for Beginners,' &c. Crown 8vo, 3s.

Practical Rudiments of the Latin Language; or, LATIN FORMS AND ENGLISH ROOTS. By JOHN ROSS, M.A., Rector of the High School of Arbroath. Third Edition. Crown 8vo, pp. 164. 1s. 6d.

Stonyhurst Latin Grammar. By Rev. JOHN GERARD. Second Edition. Fcap. 8vo, pp. 199. 3s.

Introduction to the Writing of Greek. For the Use of Junior Classes. By Sir D. K. SANDFORD, A.M., D.C.L. New Edition. Crown 8vo, 3s. 6d.

Rules and Exercises in Homeric and Attic Greek, to which is added a short System of Greek Prosody. By the SAME. New Edition. Crown 8vo, 6s. 6d.

Greek Extracts, with Notes and Lexicon. For the use of Junior Classes. By the SAME. New Edition. Crown 8vo, 6s.

Greek Testament Lessons for Colleges, Schools, AND PRIVATE STUDENTS. Consisting chiefly of the Sermon on the Mount, and Parables of our Lord. With Notes and Essays. By the Rev. J. HUNTER SMITH, M.A., King Edward's School, Birmingham. Crown 8vo, with Maps. 6s.

The Principles of Singing. A Practical Guide for Vocalists and Teachers. With course of Vocal Exercises. By ALBERT B. BACH. Second Edition. With Portrait of the Author. Crown 8vo, 6s.

Mr Stormonth's Dictionaries.

AN ETYMOLOGICAL AND PRONOUNCING

Dictionary of the English Language. Including a very Copious Selection of Scientific, Technical, and other Terms and Phrases. Designed for Use in Schools and Colleges, and as a Handy Book for General Reference. By the Rev. JAMES STORMONTH. The Pronunciation carefully revised by the Rev. P. H. PHELP, M.A. Twelfth Edition, revised, with a new and enlarged Supplement. Crown 8vo, pp. 795. 7s. 6d.

"This Dictionary is admirable. The etymological part especially is good and sound. . . . The work deserves a place in every English school, whether boys' or girls'."—*Westminster Review*.

"A full and complete etymological and explanatory dictionary of the English language. It is comprehensive, including not only all the words recognised by the best authorities as sterling old English, but all the new coinages which have passed into general circulation, with a great many scientific terms, and those which come under the designation of slang. . . . The pronunciation is carefully and clearly marked in accordance with the most approved modern usage, and in this respect the Dictionary is most valuable and thoroughly reliable. As to the etymology of words, it is exhibited in a form that fixes itself upon the memory, the root-words showing the probable origin of the English words, their primary meaning, and their equivalents in other languages. Much useful information and instruction relative to prefixes, postfixes, abbreviations, and phrases from the Latin, French, and other languages, &c., appropriately follow the Dictionary, which is throughout beautifully and most correctly printed."—*Civil Service Gazette*.

"A really good and valuable dictionary."—*Journal of Education*.

"I am happy to be able to express—and that in the strongest terms of commendation—my opinion of the merits of this Dictionary. Considering the extensive field which it covers, it seems to me a marvel of painstaking labour and general accuracy. With regard to the scientific and technical words so extensively introduced into it, I must say, that in this respect I know no Dictionary that so satisfactorily meets a real and widely felt want in our literature of reference. I have compared it with the large and costly works of Latham, Wedgwood, and others, and find that in the fulness of its details, and the clearness of its definitions, it holds its own even against them."—*Richard D. Graham, Esq., English Master, College for Daughters of Ministers of the Church of Scotland and of Professors in the Scottish Universities*.

The Handy School Dictionary. For Elementary Schools, and as a Pocket Reference Dictionary.

[*New Edition in preparation.*]

History.

Commentaries on the History of England.

FROM THE EARLIEST TIMES TO 1865. By MONTAGU BURROWS, Chichele Professor of Modern History in the University of Oxford; Captain R.N.; F.S.A., &c.; "Officier de l'Instruction Publique," France. Crown 8vo, 7s. 6d.

Epitome of Alison's History of Europe, for the USE OF SCHOOLS. 30th Thousand. Post 8vo, pp. 604. 7s. 6d.

The Eighteen Christian Centuries. By the Rev. JAMES WHITE. Seventh Edition. Post 8vo, with Index. 6s.

History of France, from the Earliest Times. By the SAME. Sixth Thousand. Post 8vo, with Index. 6s.

History of India: from the Earliest Period to the PRESENT TIME. By JOHN CLARK MARSHMAN, C.S.I. New Edition, with Map. Post 8vo, pp. 596. 6s.

Mathematics.

Practical Arithmetical Exercises. For SENIOR PUPILS IN SCHOOLS. Containing upwards of 8000 Examples, consisting in great part of Problems, and 750 Extracts from Examination Papers. Second Edition, Revised. Crown 8vo, 364 pages, 3s. *With Answers*, 3s. 6d.

Primer of Geometry. An Easy Introduction to the Propositions of Euclid. By FRANCIS CUTHBERTSON, M.A., LL.D. 6th Edition. 1s. 6d. *Answers* sold separately, price 9d.

The Theory of Arithmetic. By DAVID MUNN, F.R.S.E., Mathematical Master, Royal High School of Edinburgh. Crown 8vo, pp. 294. 5s.

Treatise on Arithmetic, with numerous Exercises for Teaching in Classes. By JAMES WATSON, one of the Masters of Heriot's Hospital. A New Edition. Fcap, 1s.

Elementary Algebra. Crown 8vo, 288 pp. Crown 8vo, cloth, 2s. *With Answers*, 2s. 6d. [Immediately.]

Mensuration. 128 pp., cloth, 1s. Also in Two Parts. Pt. I., Parallelograms and Triangles. 64 pp. Paper, 4d.; cloth, 6d. Pt. II., Circles and Solids. 64 pp. Paper, 4d.; cloth, 6d. *Answers* may be had separately, price 2d. each Part.

Handbook of Mental Arithmetic. With 7200 Examples and Answers. Large crown 8vo, 264 pp., 2s. 6d. Also in Six Parts, limp cloth, price 6d. each.

Geography.

Eleventh Thousand.

Manual of Modern Geography: Mathematical, PHYSICAL, AND POLITICAL; on a new plan, embracing a complete development of the River Systems of the Globe. By the Rev. ALEXANDER MACKAY, LL.D., F.R.G.S. Revised to date of publication. Eleventh Thousand. Crown 8vo, pp. 688. 7s. 6d.

This volume—the result of many years' unremitting application—is specially adapted for the use of Teachers, Advanced Classes, Candidates for the Civil Service, and proficients in geography generally.

Fifty-Fifth Thousand.

Elements of Modern Geography. By the SAME. Revised to the present time. Crown 8vo, pp. 300. 3s.

The 'Elements' form a careful condensation of the 'Manual,' the order of arrangement being the same, the river-systems of the globe playing the same conspicuous part, the pronunciation being given, and the results of the latest census being uniformly exhibited. This volume is now extensively introduced into many of the best schools in the kingdom.

One Hundred and Ninety-First Thousand.

Outlines of Modern Geography. By the SAME. Revised to the present time. 18mo, pp. 128. 1s.

These 'Outlines'—in many respects an epitome of the 'Elements'—are carefully prepared to meet the wants of beginners. The arrangement is the same as in the Author's larger works. Minute details are avoided, the broad outlines are graphically presented, the accentuation marked, and the most recent changes in political geography exhibited.

Eighteenth Edition.

The Intermediate Geography. Intended as an Intermediate Book between the Author's 'Outlines of Geography' and 'Elements of Geography.' By the SAME. Revised to the present time. Crown 8vo, pp. 238. 2s.

One Hundred and Fifth Thousand.

First Steps in Geography. By the SAME. Revised to the present time. 18mo, pp. 56. Sewed, 4d.; in cloth, 6d.

Geography of the British Empire. By the SAME. 3d.

Elements of Physiography. By the SAME. *See page 7.*

Physical Geography.

Thirteenth Edition, Revised.

Introductory Text-Book of Physical Geography.

With Sketch-Maps and Illustrations. By DAVID PAGE, LL.D., &c. Revised by Professor CHARLES LAPWORTH. 2s. 6d.

"The divisions of the subject are so clearly defined, the explanations are so lucid, the relations of one portion of the subject to another are so satisfactorily shown, and, above all, the bearings of the allied sciences to Physical Geography are brought out with so much precision, that every reader will feel that difficulties have been removed, and the path of study smoothed before him."—*Athenæum*.

"Whether as a school-book or a manual for the private student, this work has no equal in our Educational literature."—*Iron*.

Advanced Text-Book of Physical Geography.

By the SAME. With Engravings. Third Edition. Revised by Professor CHARLES LAPWORTH. 5s.

"A thoroughly good Text-Book of Physical Geography."—*Saturday Review*.

Examinations on Physical Geography. A Pro-

gressive Series of Questions, adapted to the Introductory and Advanced Text-Books of Physical Geography. By the SAME. Sixth Edition. 9d.

Elements of Physiography. By the Rev. ALEX.

MACKAY, LL.D., F.R.G.S., Author of 'A Manual of Modern Geography, Mathematical, Physical, and Political,' &c. New Edition. Rewritten and Enlarged. With specially prepared Diagrams and other Illustrations. Crown 8vo. [*Immediately*].

Comparative Geography. By CARL RITTER.

Translated by W. L. GAGE. Fcap, 3s. 6d.

A First Book on Physical Geography. For

Use in Schools. 64 pp. 4d.

Botany.

A Manual of Botany, Anatomical and Physio-

logical. For the Use of Students. By ROBERT BROWN, M.A., PH.D., F.R.G.S. Crown 8vo, with numerous Illustrations. 12s. 6d.

"We have no hesitation in recommending this volume to our readers as being the best and most reliable of the many works on Botany yet issued. . . . His manual will, if we mistake not, be eagerly consulted and attentively studied by all those who take an interest in the science of botany."—*Civil Service Gazette*.

Geology.

New Edition, Revised and Enlarged.

Introductory Text-Book of Geology. By DAVID

PAGE, LL.D., &c., Professor of Geology in the Durham University College of Physical Science, Newcastle. New Edition, revised by Professor CHARLES LAPWORTH, LL.D., Mason Science College, Birmingham. *[In preparation.]*

"It has not been our good fortune to examine a text-book on science of which we could express an opinion so entirely favourable as we are enabled to do of Mr Page's little work."—*Athenæum*.

New Edition, Revised.

Advanced Text-Book of Geology, Descriptive and

INDUSTRIAL. By the SAME. Revised by Professor LAPWORTH.

[In the press.]

"We have carefully read this truly satisfactory book, and do not hesitate to say that it is an excellent compendium of the great facts of Geology, and written in a truthful and philosophic spirit."—*Edinburgh Philosophical Journal*.

"As a school-book nothing can match the Advanced Text-Book of Geology by Professor Page of Newcastle."—*Mechanics' Magazine*.

"We know of no introduction containing a larger amount of information in the same space, and which we could more cordially recommend to the geological student."—*Athenæum*.

Tenth Edition.

The Geological Examiner. A Progressive Series

of Questions, adapted to the Introductory and Advanced Text-Books of Geology. Prepared to assist Teachers in framing their Examinations, and Students in testing their own Progress and Proficiency. By the SAME. 9d.

"Few of our handbooks of popular science can be said to have greater or more decisive merit than those of Mr Page on Geology and Palæontology. They are clear and vigorous in style, they never oppress the reader with a pedantic display of learning, nor overwhelm him with a pompous and superfluous terminology; and they have the happy art of taking him straightway to the face of nature herself, instead of leading him by the tortuous and bewildering paths of technical system and artificial classification."—*Saturday Review*.

German.

A Handy Manual of German Literature. For Schools, Civil Service Competitions, and University Local Examinations. By M. F. REID. Fcap. cloth, 3s.

A Treasury of the English and German Languages. Compiled from the best Authors and Lexicographers in both Languages. Adapted to the Use of Schools, Students, Travellers, and Men of Business; and forming a Companion to all German-English Dictionaries. By JOSEPH CAUVIN, LL.D. & PH.D., of the University of Göttingen, &c. Crown 8vo, 7s. 6d., bound in cloth.

Zoology.

A Manual of Zoology, for the Use of Students.

With a General Introduction on the Principles of Zoology. By HENRY ALLEYNE NICHOLSON, M.D., D.Sc., F.L.S., F.G.S., Regius Professor of Natural History in the University of Aberdeen. Seventh Edition, rewritten and greatly enlarged. Post 8vo, with 555 Engravings on Wood. Pp. 956. 18s.

"It is the best manual of zoology yet published, not merely in England, but in Europe."—*Pall Mall Gazette*.

"The best treatise on zoology in moderate compass that we possess."—*Lancet*.

Text-Book of Zoology, for Junior Students. By

the SAME. Fifth Edition, rewritten and enlarged. Crown 8vo, with 358 Engravings on Wood. 10s. 6d.

"This capital introduction to natural history is illustrated and well got up in every way. We should be glad to see it generally used in schools."—*Medical Press and Circular*.

Introductory Text-Book of Zoology, for the Use

of Junior Classes. By the SAME. Sixth Edition, revised and enlarged, with 180 Engravings. 3s.

"Very suitable for junior classes in schools. There is no reason why any one should not become acquainted with the principles of the science, and the facts on which they are based, as set forth in this volume."—*Lancet*.

"Nothing can be better adapted to its object than this cheap and well-written Introduction."—*London Quarterly Review*.

Outlines of Natural History, for Beginners ; being

Descriptions of a Progressive Series of Zoological Types. By the SAME. Third Edition. With 52 Engravings. 1s. 6d.

"There has been no book since Patterson's well-known 'Zoology for Schools' that has so completely provided for the class to which it is addressed as the capital little volume by Dr Nicholson."—*Popular Science Review*.

Introduction to the Study of Biology. By the

SAME. Crown 8vo, with numerous Engravings. 5s.

"Admirably written and fairly illustrated, and brings within the compass of 160 pages the record of investigations and discoveries scattered over as many volumes. Seldom indeed do we find such subjects treated in a style at once so popular and yet so minutely accurate in scientific detail."—*Scotsman*.

Palæontology.

A Manual of Palæontology, for the Use of Students.

With a General Introduction on the Principles of Palæontology.
By Professor H. ALLEYNE NICHOLSON, Aberdeen, and RICHARD
LYDEKKER, B.A., F.G.S., &c. Third Edition. Entirely rewritten
and greatly enlarged. 2 vols. 8vo, with 1419 Engravings. 63s.

"The work furnishes the student with an excellent summary of the leading principles of palæontological science—by far the most complete which has ever been published in the English language—and any one who wishes to gain either a general knowledge of the past life of the earth, or a guiding key to any particular division, cannot do better than make use of its assistance."—*Geological Magazine*.

"This book will be found to be one of the best of guides to the principles of Palæontology and the study of organic remains."—*Athenæum*.

"The most comprehensive and valuable text-book yet published on the methods and results of palæontological research.....The whole subject of palæontology is treated with a singular fulness and richness of information, the result both of wide research and original investigation."—*Scotsman*.

The Ancient Life - History of the Earth. An

Outline of the Principles and Leading Facts of Palæontological Science. By HENRY ALLEYNE NICHOLSON, M.D., D.Sc., F.L.S., F.G.S., Regius Professor in the University of Aberdeen. With a Glossary and Index. Crown 8vo, with 270 Engravings. 10s. 6d.

"As a text-book of the historical phase of palæontology it will be indispensable to students, whether specially pursuing geology or biology."—*Quarterly Journal of Science*.

"Scarcely any recommendation of ours can add to the interest with which all students in natural history will receive the present volume."—*Athenæum*.

Popular Chemistry.

Professor Johnston's Chemistry of Common Life.

New Edition, revised and brought down to the present time.
By A. H. CHURCH, M.A. Oxon., Author of 'Food, its Sources, Constituents, and Uses,' &c. With Maps and 102 Engravings.
Crown 8vo, pp. 618. 7s. 6d.

"No popular scientific work that has ever been published has been more generally and deservedly appreciated than the late Professor Johnston's 'Chemistry of Common Life.'.....It remains unrivalled as a clear, interesting, comprehensive, and exact treatise upon the important subjects with which it deals."—*Mark Lane Express*.

"The established reputation of this volume is not merely maintained, but its value is considerably increased by the care with which every subject has been posted up to the date of publication."—*Athenæum*.

Agriculture.

Johnston's Elements of Agricultural Chemistry. From the Edition by Sir CHARLES A. CAMERON, M.D., F.R.C.S.I. Revised and brought down to date by C. M. AIKMAN, M.A., D.Sc., &c. 17th Edition. Crown 8vo, 6s. 6d.

"It would be a happy day, not merely for the agricultural interest, but for England in general, if farming were generally carried on in the light of the law laid down in these pages."—*Chemical News*.

Johnston's Catechism of Agricultural Chemistry. From the Edition by Sir C. A. CAMERON. Revised and enlarged by C. M. AIKMAN. With Engravings. 92d Thousand. Crown 8vo, 1s.

"The volume contains a wealth of information, and would be much prized by any student who seeks acquaintance with its pages."—*Yorkshire Gazette*.

"Should be in the hands of all students of agriculture, and practical farmers would derive great benefit from its perusal."—*Schoolmaster*.

"The revision and enlargement has been excellently carried out, so that it is still certain to remain a favourite book for teaching and reference."—*Mark Lane Express*.

Manures and the Principles of Manuring. By C. M. AIKMAN, M.A., D.Sc., Professor of Chemistry, Glasgow Veterinary College; Examiner in Chemistry, University of Glasgow, &c. Crown 8vo, 6s. 6d.

"Agreeably fresh in theory, and pleasant in the manner of expression..... An eminently useful work."—*Farmer and Stockbreeder*.

Farmyard Manure: Its Nature, Composition, and Treatment. By the SAME AUTHOR. Crown 8vo, 1s. 6d.

"The little manual before us will be found of great assistance in this study. It deals exhaustively with this subject, complex though it be, and says quite sufficient on every point of importance to enable any one of ordinary intelligence to arrive at just conclusions as to the source of value in his farmyard manure."—*Agricultural Economist*.

"A perusal of Professor Aikman's little book, with the use of his own common-sense, will enable any practical farmer to hit off the 'golden mean' in manuring."—*Farming Gazette*.

Stephens' Catechism of Practical Agriculture.

Twenty-second Thousand, revised and largely rewritten by JAMES MACDONALD, F.R.S.E., Secretary of the Highland and Agricultural Society; Editor of the Sixth Edition of 'The Book of the Farm.' With numerous Illustrations. Crown 8vo, 1s.

"For those who desire to know the elements of agriculture and the work and operations incidental to the four seasons,.....this capital shilling's worth will be found well suited."—*Field*.

Mental Philosophy.

Lectures on Metaphysics. By Sir WILLIAM HAMILTON, Bart., Professor of Logic and Metaphysics in the University of Edinburgh. Edited by the Very Rev. H. L. MANSELL, LL.D., Dean of St Paul's, and JOHN VEITCH, LL.D., Professor of Logic and Rhetoric, Glasgow. Seventh Edition. 2 vols. 8vo, 24s.

Lectures on Logic. By Sir WILLIAM HAMILTON, Bart. Edited by the SAME. Third Edition. 2 vols. 8vo, 24s.

Discussions on Philosophy and Literature, EDUCATION AND UNIVERSITY REFORM. By Sir WILLIAM HAMILTON, Bart. Third Edition. 8vo, 21s.

Philosophical Works of the late James FREDERICK FERRIER, B.A. Oxon., LL.D., Professor of Moral Philosophy and Political Economy in the University of St Andrews. New Edition. 3 vols. crown 8vo, 34s. 6d.

The following are sold separately :—

INSTITUTES OF METAPHYSIC. Third Edition. 10s. 6d.

LECTURES ON THE EARLY GREEK PHILOSOPHY. Third Edition. 10s. 6d.

PHILOSOPHICAL REMAINS, INCLUDING THE LECTURES ON EARLY GREEK PHILOSOPHY. Edited by Sir ALEX. GRANT, Bart., D.C.L., and Professor LUSHINGTON. 2 vols. 24s.

Port Royal Logic. Translated from the French ; with Introduction, Notes, and Appendix. By THOMAS SPENCER BAYNES, LL.D., Professor of Logic and English Literature in the University of St Andrews. Tenth Edition. 12mo, 4s.

Method, Meditations, and Principles of Philosophy OF DESCARTES. Translated from the original French and Latin. With a New Introductory Essay, Historical and Critical, on the Cartesian Philosophy. By JOHN VEITCH, LL.D., Professor of Logic and Rhetoric in the University of Glasgow. Tenth Edition. 12mo, 6s. 6d.

Historical Philosophy in France and French BELGIUM AND SWITZERLAND. By ROBERT FLINT, Corresponding Member of the Institute of France, Hon. Member of the Royal Society of Palermo, Professor in the University of Edinburgh, &c. 8vo, 21s.

Mental Philosophy.

John Stuart Mill. A STUDY OF HIS PHILOSOPHY.

By CHARLES DOUGLAS, M.A., D.Sc., Lecturer in Moral Philosophy, and Assistant to the Professor of Moral Philosophy in the University of Edinburgh. Small crown 8vo, 4s. 6d. *net*.

Knowing and Being. ESSAYS IN PHILOSOPHY.

First Series. By JOHN VEITCH, LL.D., Professor of Logic and Rhetoric in the University of Glasgow. Crown 8vo, 5s.

Dualism and Monism; AND OTHER ESSAYS. Essays in Philosophy. Second Series. By the SAME AUTHOR. With an Introduction by R. M. WENLEY. Crown 8vo, 4s. 6d. *net*.

Institutes of Logic. By the SAME AUTHOR. Post 8vo, 12s. 6d.

A Study of Ethical Principles. By JAMES SETH, M.A., Professor of Philosophy in Brown University, U.S.A. Second Edition, Revised. Post 8vo, 10s. 6d. *net*.

Scottish Philosophy. A Comparison of the Scottish and German Answers to Hume. Balfour Philosophical Lectures, University of Edinburgh. By ANDREW SETH, LL.D., Professor of Logic and Metaphysics in Edinburgh University. Second Edition. Crown 8vo, 5s.

Hegelianism and Personality. Balfour Philosophical Lectures. Second Series. Second Edition. Crown 8vo, 5s.

The Ethics of Naturalism. Being the Shaw Fellowship Lectures, 1884. By W. R. SORLEY, M.A., Fellow of Trinity College, Cambridge, Professor of Moral Philosophy in the University of Aberdeen. Crown 8vo, 6s.

Socrates and Christ : A STUDY IN THE PHILOSOPHY OF RELIGION. By R. M. WENLEY, M.A., D.Sc., D.Phil., Professor of Philosophy in the University of Michigan, U.S.A. Crown 8vo, 6s.

Aspects of Pessimism. By the SAME AUTHOR. Crown 8vo, 6s.

Philosophical Classics for English Readers.

Edited by WILLIAM KNIGHT, Professor of Moral Philosophy
University of St Andrews. In crown 8vo, cloth boards, with Por-
traits, price 3s. 6d. each.

CONTENTS.—Descartes, by Professor J. P. Mahaffy, Dublin. Butler, by the Rev. W. Lucas Collins, M.A. Berkeley, by Professor A. Campbell Fraser, Edinburgh. Fichte, by Professor Adamson, M.A., Aberdeen. Kant, by Professor Wallace, Merton College, Oxford. Hamilton, by Professor Veitch, Glasgow. Hegel, by the Master of Balliol. Leibniz, by John Theodore Merz, Vico, by Professor Flint, D.D., Edinburgh. Hobbes, by Professor Croon, Robertson, London. Hume, by the Editor. Spinoza, by the Very Rev. Principal Caird, Glasgow. Bacon: Part I. The Life; Part II. Philosophy, by Professor Nichol, Glasgow. Locke, by Professor Campbell Fraser, Edinburgh.

Ancient Classics for English Readers. Edited

by the Rev. W. LUCAS COLLINS, M.A. Complete in 28 vols.
price 2s. 6d. each, in cloth (sold separately); or bound in 14 vols.
with calf or vellum back, for £3, 10s.

CONTENTS.—Homer: The Iliad, by the Editor. Homer: The Odyssey, by the Editor. Herodotus, by G. C. Swayne, M.A. Xenophon, by Sir Alexander Grant, Bart. Euripides, by W. B. Donne. Aristophanes, by the Editor. Plato, by Clifton W. Collins, M.A. Lucian, by the Editor. Æschylus, by Reginald S. Copleston, D.D. (now Bishop of Colombo). Sophocles, by Clifton W. Collins, M.A. Hesiod and Theognis, by the Rev. J. Davies, M.A. Greek Anthology, by Lord Neaves. Virgil, by the Editor. Horace, by Sir Theodore Martin, K.C.B. Juvenal, by Edward Walford, M.A. Plautus and Terence, by the Editor. The Commentaries of Cæsar, by Anthony Trollope. Tacitus, by W. B. Donne. Cicero, by the Editor. Pliny's Letters, by the Rev. Alfred Church, M.A., and the Rev. W. J. Brodribb, M.A. Livy, by the Editor. Ovid, by the Rev. A. Church, M.A. Catullus, Tibullus, and Propertius, by the Rev. James Davies, M.A. Demosthenes, by the Rev. W. J. Brodribb, M.A. Aristotle, by Sir Alexander Grant, Bart., LL.D. Thucydides, by the Editor. Lucretius, by W. H. Mallock. Pindar, by the Rev. F. D. Morice, M.A.

Foreign Classics for English Readers. Edited

by MRS OLIPHANT. In crown 8vo volumes, each price 2s. 6d.

CONTENTS.—Dante, by the Editor. Voltaire, by General Sir E. B. Hamley. Pascal, by Principal Tulloch. Petrarch, by Henry Reeve. Goethe, by A. Hayward, Q.C. Molière, by the Editor and F. Tarver, M.A. Montaigne, by the Rev. W. Lucas Collins, M.A. Rabelais, by Sir Walter Besant. Calderon, by E. J. Hasell. Saint Simon, by Clifton W. Collins, M.A. Cervantes, by the Editor. Corneille and Racine, by Henry M. Trollope. Madame de Sévigné, by Miss Thackeray. La Fontaine, and other French Fabulists, by Rev. W. Lucas Collins, M.A. Schiller, by James Sime. Tasso, by E. J. Hasell. Rousseau, by Henry Graham. Alfred de Musset, by C. F. Oliphant.

BLACKWOODS'
NEW EDUCATIONAL SERIES
FOR ELEMENTARY SCHOOLS.

Historical Readers.

STANDARDS III. TO VII.

With Numerous Illustrations and Maps.

Short Stories from English History. Pp. 160. 1s.

First Historical Reader. BRITAIN AND ENGLAND.

From before Christ to 1154 A.D. Pp. 160. 1s.

Second Historical Reader. From HENRY THE SECOND to ELIZABETH. Pp. 224. 1s. 4d.

Third Historical Reader. From JAMES I. to QUEEN VICTORIA. Pp. 256. 1s. 6d.

A Complete History of England. *For Junior Classes.* BRITAIN AND ENGLAND. From before Christ to 1884 A.D. With Notes and Genealogical Tables. Pp. 206. 1s. 4d.

Geographical Readers.

STANDARDS I. TO VII.

Profusely Illustrated with Maps and Engravings.

The Geographical Primer. Pp. 96. 9d.

Book I. Pp. 96. 9d.

Book II. ENGLAND AND WALES. Pp. 156. 1s.

Book III. SCOTLAND, IRELAND, BRITISH NORTH AMERICA, AND AUSTRALASIA. Pp. 192. 1s. 3d.

Book IV. THE CONTINENT OF EUROPE. Pp. 256. 1s. 6d.

Book V. ASIA, AFRICA, AMERICA, AND OCEANIA. Pp. 256. 1s. 6d.

Book VI. THE OCEANS, SEAS, TIDES, WINDS, AND CURRENTS OF THE WORLD, WITH LESSONS ON THE HEAVENLY BODIES. Pp. 256. 1s. 9d.

School Recitation Books.

Books I. and II.—Each 2d. | Books III. and IV.—Each 3d.

Books V. and VI.—Each 4d.

Standard Authors.

With Notes and Illustrations.

'Robinson Crusoe.' Pp. 192. 1s. 3d. — 'Tanglewood Tales.' Pp. 160. 1s. 2d. — 'Our Village.' Pp. 144. 1s. 2d. — 'Vicar of Wakefield.' Pp. 160. 1s. 2d.

Standard Readers.

Revised Edition. With Supplementary Pages. Profusely Illustrated.

The First Picture Primer. Pp. 32. Sewed, 2d.; cloth, 3d.

The Second Picture Primer. Pp. 32. Sewed, 2d.; cloth, 3d.

Picture Reading - Sheets. FIRST AND SECOND SERIES.

16 Sheets each, unmounted, price 3s. 6d. Mounted on 8 boards, 14s.; or the 16 Sheets laid on cloth, varnished, and mounted on a roller, 17s. 6d.

The Infant Picture Reader. Pp. 64. Cloth, limp, 6d.

Book I. 8d.

Book III. 1s.

Book V. 1s. 4d.

Book II. 9d.

Book IV. 1s. 3d.

Book VI. 1s. 6d.

READING BOOKS FOR THE SCOTCH CODE.

With Maps and Illustrations.

The Combined Historical and Geographical Reader.

For STANDARD III. 190 pp. 1s.

History of Great Britain FROM THE UNION OF THE CROWNS

TO THE DEATH OF QUEEN ANNE. STANDARD IV. 176 pp. 1s.

History of Great Britain FROM GEORGE I. TO THE PRESENT

REIGN. STANDARDS V. and VI. 192 pp. 1s.

With Introduction, Notes, and Life of the Author.

Aytoun's 'Edinburgh after Flodden.' 2d.; cloth, 3½d.

Aytoun's 'The Execution of Montrose.' 2d.; cloth, 3½d.

Aytoun's 'The Burial-March of Dundee.' 2d.; cloth, 3½d.

Aytoun's 'Island of the Scots.' 2d.; cloth, 3½d.

Manual Instruction—Woodwork. DESIGNED TO

MEET THE REQUIREMENTS OF THE MINUTE OF THE SCIENCE AND

ART DEPARTMENT ON MANUAL INSTRUCTION. By GEORGE ST

JOHN, Undenominational School, Handsworth, Birmingham.

With 100 Illustrations. Fcap. 8vo, 1s.

The Series of Elementary Educational Works also embraces Arithmetic, Grammar and Analysis, Stories for Composition, Poetry for Recitation, Physical Geography, Test Cards, &c.

A complete Catalogue may be had, post free, on application.

WILLIAM BLACKWOOD & SONS, EDINBURGH AND LONDON.

5392

